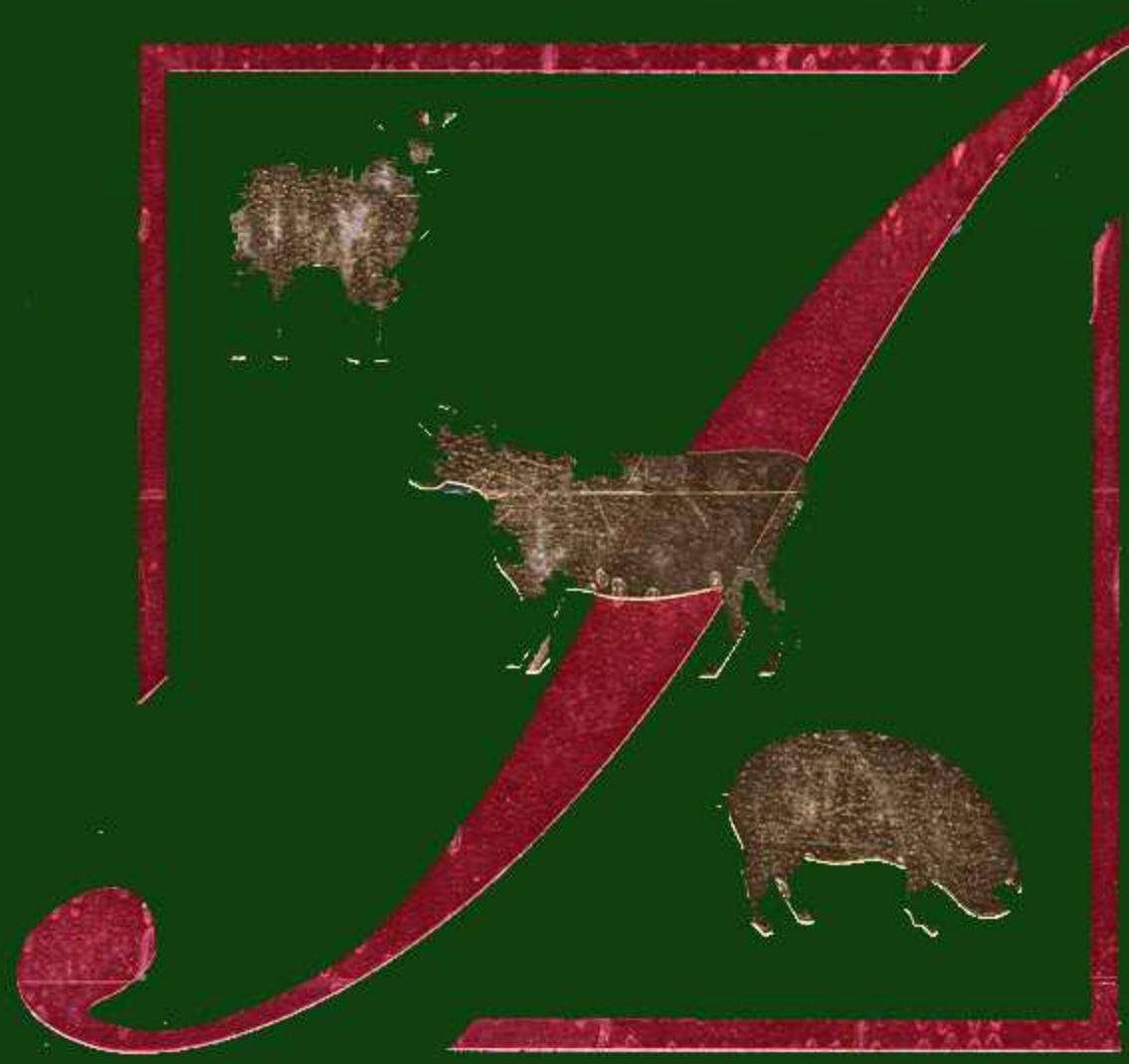
THIRD EDITION

Herd Health

FOOD ANIMAL PRODUCTION MEDICINE



OTTO M. RADOSTITS

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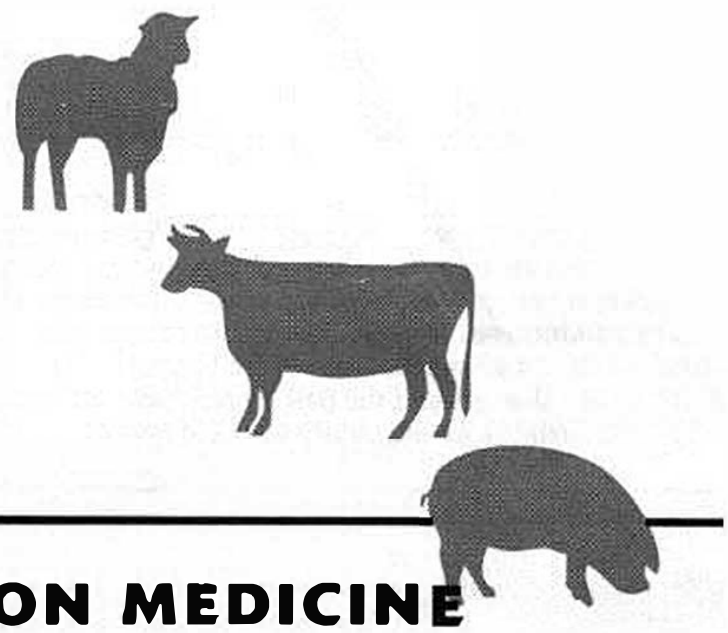

FOOD ANIMAL PRODUCTION MEDICINE

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To

Douglas Charles Blood

Professor Emeritus, University of Melbourne

who provided the leadership and inspiration to many of his students in order to strive to master large animal medicine and its application to the health management of food-producing animals

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Preface

Herd Health: Food Animal Production Medicine describes the role of the veterinarian in the management of animal health and production in dairy and beef cattle herds, beef feedlots, swine herds, and sheep flocks. It is about the efficient production of food-producing animals. The preface to the first edition of this book (1985) stated, "It is our conviction that the present rapid growth of animal health management services provided by veterinarians to herds and flocks will continue and that within a decade this form of veterinary activity will dominate food animal practice." The intent of the first edition of this book was to provide a starting point for undergraduate veterinary students and practitioners to gather the principles and techniques for the basis of food-animal health management programs. Numerous readers who have examined the first and second editions have commented that the information in the books provided a sound basis for the development of species-specific health management programs. The third edition has updated the text as a source of information for the new challenge in the delivery of health management programs.

Since the publication of the first edition in 1985 and the second edition in 1994, a large volume of information has been published on health and production of the food-producing animals. More articles on planned animal health and production programs appear in journals each year, and relevant continuing veterinary education programs are devoting an increasing proportion of their scientific programs to production-oriented animal health management. The volume of literature on the health and production of food-producing animals is large and complex, involving many disciplines that must be integrated. For this edition the task of identifying and integrating necessary and useful information and guidance for the undergraduate veterinary student and the practitioner was a major challenge. The most difficult task was to avoid rewriting existing textbooks on veterinary medicine, animal husbandry, nutrition and housing, and animal welfare while selecting appropriate information to be included. It is now obvious that becoming a species specialist with a comprehensive understanding of an industry, such as the dairy cattle industry, is the only hope of mastering the knowledge and skills required to provide a high-quality health management service with emphasis on the integration of animal health and production management. The targets of animal health and performance for each species were reviewed and revised according to published information. Much new information on the factors that interfere with optimum performance has been included. The methods and strategies for economical corrective action are also outlined for each species.

Rural veterinary practitioners worldwide are recognizing the need to change their attitudes about the services they provide. The traditional role of the healer of individual sick animals is gradually being complemented by the delivery of totally integrated health management programs concentrating on the performance of the herd. Veterinary colleges are revising their curricula to meet this new challenge. One of the objectives of this book is to provide a framework for a course curriculum in animal health and production management. This book is written for veterinary students and graduate veterinarians who want to study the concepts involved in development and delivery of health management programs. A common theme carried throughout this book is that sound health management programs will lead to the most efficient, economical, and profitable production of livestock while providing for the welfare needs of the animals and ensuring the product's quality.

Veterinary epidemiology has become a major influence, providing much of the new information included in this revision. Many observational studies and field trials have been performed to study the relationships between risk factors and disease and their effects on animal production. Epidemiological techniques have become important tools for developing health management programs. The collection and analysis of farm data for the implementation of health plans and actions, as well as the ongoing monitoring of the performance outcome, inherently imply the use of these tools by veterinary practitioners. In order to accomplish these activities, the computer has become a major factor in the application of epidemiological principles to herd problems. Computers are now commonplace in veterinary practice and an integral part of health management programs.

I gratefully acknowledge the contributors who have revised or rewritten the chapters from the second edition that evolved into those in the third edition.

I revised Chapter 1, "Principles of Health Management in Food-Producing Animals." The chapter outlines the principles of production-oriented medicine in food-producing animals and explains the objectives and methods used in the book. Some emphasis is given to the public health concerns about the intensification of animal agriculture and the need for veterinarians to become proactive in this area. Chapter 2, "Quantitative Tools for Production-Oriented Veterinarians," was written by Dr. Barrett Slenning. It describes in user-friendly terms the mathematical techniques used in animal health and production management. Chapter 3, "Records Systems and Herd Monitoring in Production-Oriented Health Management Programs in Food-Producing Animals," was written by Drs. Jeff Reneau and Mark Kinsel. It describes the principles of monitoring animal health and production data and generating useful information for decision making, which have become important aspects of production-oriented medicine. Chapter 4, "Control of Infectious Diseases of Food-Producing Animals," outlines the principles of control of infectious diseases of food-producing animals that should help the veterinarian plan disease control on a year-round basis and as an integral part of a totally integrated animal health management service to the producer.

Chapter 5, "Investigation of Disease Outbreaks and Suboptimum Productivity," is a new chapter written by Dr. Cheryl Waldner. It emphasizes the importance of using the tools of epidemiology in the investigation of disease outbreaks and suboptimum productivity in herds.

Chapter 6, "Health and Production Management in Dairy Herds," was revised by Dr. Pam Ruegg and deals with

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the general aspects of dairy cattle health management. Major changes have taken place in the dairy cattle industry, and these have been described and discussed in the chapter. Chapter 7, "Maintaining Reproductive Efficiency in Dairy Cattle," revised by Drs. Peter Farin and Barrett Slenning, emphasizes monitoring reproductive performance in the dairy herd. Chapter 8, "Culling and Genetic Improvement Programs in Dairy Cattle," was completely revised by Drs. Brian Radke and George Shook. The chapter represents one of few sources of such information for dairy cattle practitioners. The computer programs now available for the selection of bulls provide an opportunity for veterinarians to offer this advisory service to dairy producers as part of a complete animal health management program. New approaches to culling dairy cattle are included in the section written by Dr. Radke. Chapter 9, "Health Management of Dairy Calves and Replacement Heifers," was revised by Dr. Judson Heinrichs and myself. The section dealing with dairy heifer replacements, which represents a growing activity in dairy health management, was expanded. Chapter 10, "Mastitis Control in Dairy Herds," was completely revised by Dr. Ronald Erskine and emphasizes a 10-point control program. Chapter 11, "Dairy Cattle Nutrition," was written by Dr. Brian Gerloff and is a revision of the original. Chapter 12, "Housing and Environment for Dairy Cattle," has also been revised by Dr. William Bickert and myself and includes information on the relationship between housing and lameness in diary cattle.

Chapter 13, "Health and Production Management in Beef Cattle Breeding Herds," was written by Drs. Peter Chenoweth and Michael Sanderson. The emphasis is on the animal health strategies necessary to achieve optimum reproductive performance and calf survival in the herd. Chapter 14, "Health and Production Management in Beef Feedlots," was revised by Drs. Robert Smith, Gerald Stokka, Dee Griffin, and myself. The strategies for the clinical management and control of acute respiratory disease in recent arrivals are a major emphasis of the chapter and are described in detail, with emphasis on the need for useful health records. Chapter 15, "Health and Production Management in Swine Herds," was revised by Drs. John Deen, Scott Dee, Robert Morrison, and myself. Revising and expanding the swine chapter was a major task because of the large amount of information being published on swine health and production. Major progress has been made in swine health and production management services provided by veterinarians. Chapter 16, "Health and Production Management in Sheep Flocks," was revised by Dr. Philip Scott and represents the activities occurring in the development of sheep health and production management programs, particularly in sheep-raising countries like New Zealand, Australia, and the United Kingdom.

Animal welfare is now a major issue in animal production, and each species chapter includes some information on the welfare aspects of health and production. Production-oriented veterinarians will need to become proactive about the welfare requirements of food-producing animals.

The possible contamination of meat and milk with residues of antimicrobials, antimicrobial-resistant bacteria, growth-enchancing hormones, and other drugs used in animal health and production management represents major food safety concerns of society. The use of antimicrobials in the feed of food animals, which may lead to the development of drug-resistant bacteria with the potential to be transferred to humans, has been addressed where appropriate. Veterinarians must become proactive and educate producers on the proper use of drugs in food-producing animals.

Many thanks are given to Linda Kraft and Tracey Gilles for typing assistance of some of the tables and reference lists.

I also thank the Western College of Veterinary Medicine and the University of Saskatchewan for providing the resources, including the excellent Veterinary Medical Library, and the patient and helpful librarians. Most of all, I thank my wife, Ruth, for her patience and encouragement.

Otto M. Radostits, DVM, MSc

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CHAPTER 1

Principles of Health Management of Food-Producing Animals

OTTO M. RADOSTITS

The knowledge and the technology are available to provide a cost-effective comprehensive health management veterinary service to production-oriented livestock producers. The delivery of the service by veterinarians is the greatest challenge facing food animal practitioners. The emphasis is changing from the treatment of disease to health and production management.

Radostits OM: A veterinary odyssey: prospects for large animal practice in the 21st century. Proceedings of the forty-fifth annual convention of the Canadian Veterinary Medical Association, Edmonton, Canada, 1993.

IMPORTANCE AND SUCCESS OF FOOD ANIMAL AGRICULTURE

Food-producing animals make important contributions to agriculture and human well being. One of the most important needs of humans is a dependable food supply. The Hudson Institute has estimated that the demand for farm products containing animal protein will double or triple in the next 40 to 50 years with the world population expected to be about 9 billion in the next 20 to 30 years. Thus there will be many opportunities for veterinarians in agribusiness (Gloyd, 1998). The efficient production of livestock that yield meat, milk, and fiber is a major concern of society in general and of sociologists, animal scientists, and animal specialists in particular.

One of the most important functions of domestic farm animals is the conversion of human-inedible forages, by-products, and crop residues into high-quality human food in the form of meat, milk, and eggs (Bradford, 1989). Much has been said and written about the low efficiencies of livestock in converting plant products into animal products, and it has been inferred that livestock production should be reduced in the interests of using that food supply for humans. However, at least two critical facts are frequently ignored. The first is that a high proportion of the plant materials converted by ruminant animals cannot be used directly by humans. The second is that a high concentration of nutrients, such as amino acids, minerals, and B-complex vitamins, are confined in animal food products, in comparison with those of plant origin. When the inputs and returns are considered, beef cattle production appears to be very inefficient on the basis of input and return of energy and protein; however, beef cattle actually convert human-inedible energy and protein in their diet into human food energy and protein, with estimated efficiencies of 57% and 109%, respectively. The corresponding values for milk production are 101% and 181%, respectively (Bradford, 1989).

The estimates just mentioned are based on production practices in developed countries, using substantial amounts of feed grains. In developed countries, livestock have an important buffering effect on cereal grain prices and food supplies. For example, the beef feedlot industry in North America developed in response to the availability of inexpensive grains because of the large increase in yields per acre, from about 1950 to 1970, associated with the adoption of new technologies for grain production. In developing countries most animal production uses no human-edible inputs. The improvement in quality and nutrient balance of human diets from the inclusion of animal products is particularly important in developing countries, where protein quantity and quality tend to be limited.

In some developing countries, where feed grains are in short supply, an increase in the use of small ruminants such as sheep and goats, which can convert a wide variety of plant products into human food energy and protein, is a major development. Another important contribution of animals in developing countries is their buffering effect on food supply and income. Herds are built up during good seasons and years and slaughtered for food during periods of drought. In some countries where credit and banking services are not available, livestock are used for their monetary value and can be sold more readily in times of need than most other commodities produced on the farm. In such an economic system, the cost of maintaining a nonproductive animal or one of low productivity is viewed differently than in a system in which animals are sold at the optimum time relative to biological efficiency and the proceeds banked (Bradford, 1989).

Some animals provide 75% to 90% of the draft power for agriculture in large regions of the world. Draft animals constitute the most important component of the animal sector in more than half of the world's countries. Because many countries lack the capital required to purchase the mechanical tractor power and fuel needed for modern mechanized agriculture, animal draft power is likely to remain an essential component of agriculture in many countries for a long time. Farm livestock also provide fertilizer in the form of manure, which may become more important in efforts to sustain soil fertility in areas that have experienced excessive erosion because of continuous tilling and cropping. Animals are also used effectively for weed control and for keeping roadsides free of accumulated vegetation. For example, goats and sheep are now being used to graze the forage under

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rubber and palm oil trees. In addition to the production of meat from a currently unused forage resource, covering millions of hectares, the grazing of sheep can reduce herbicide use and the cost of weed control. Such a practice illustrates the importance of integrating livestock production with other components of the agricultural system (Bradford, 1989).

In addition to the important biological functions performed by livestock in agricultural systems in developing countries, animals often have significant social and cultural or ethnic value. The slaughter of a ram for the annual religious festival of Islam is extremely important, with the result that a substantial portion of the annual sheep slaughter in Islamic countries occurs on one day of the year.

CHANGES IN FOOD ANIMAL AGRICULTURE

Food animal agriculture is changing, and the changes have implications for the organization of veterinary service to farm animals (Getz, 1997). First, economies of scale have emerged in the management of livestock. *The average herd size is increasing as the number of farms declines.* As a result, large animal practitioners are serving fewer but larger farms. Large farms tend to spend less on veterinary services per animal, but the total health management costs including animal health products such as drugs and vaccines are much greater on a herd basis than on smaller farms. Second, a growing number of farm operators have production contracts with agribusiness called integrators. The integrators may provide livestock, feedstuffs, and advice to many farms. The integrators may also provide veterinary services to all farms they have on contract. Growing numbers of food animal practitioners are salaried employees of corporate agribusiness integrators.

Scale in Livestock Production

In the United States, from 1974 to 1992, the average size of the farm increased remarkably and continues to increase. The average herd size at least doubled for dairy, pork, chickens, and broilers and nearly doubled for turkeys. The growth in average herd size paralleled the decline in the number of farms. With the development of new production methods, the average cost of production shifts downward. Producers who fail to change production methods may still have the old average cost structure and may suffer economic losses. The process of technical change improves the welfare of consumers by making livestock products available at lower costs. Farming remains economically profitable for those who adopt the new scale and techniques. In fact, farms that innovate first—the *early adopters*—may enjoy extraordinary economic profits for a time until the industry fully adjusts to the new technologies. Farms that do not adopt the new methods will be economically disadvantaged. During the same period, all of the real livestock prices fell by more than 30%. The real price of milk fell by 47%, beef cattle (live weight) fell by 43%, and pigs fell by 60%. The magnitude of the price decline over the 18 years in question was so substantial that farms that did not adjust their production methods have suffered dramatically lower net incomes. Farmers will say, "It is very tough to make a living out there because of the low prices for commodities while the costs of inputs have continued to increase."

CONTEMPORARY ISSUES IN FOOD ANIMAL AGRICULTURE

Although food-producing animals contribute in many important ways to human welfare, they also are a source of potential problems. Livestock, particularly nonruminants, can compete with humans for available human-edible food supplies, such as cereal grains and other plant products. Ironically, whereas there is concern about livestock using human-edible food, a major concern in developed countries is the overproduction of meat, milk, and wool. World surpluses of animal products have come to dominate national and international agricultural policies. Consumer concern about the potential health hazards associated with the consumption of animal products can increasingly dictate the quality and quantity of the outputs. The perceived problems of overgrazing and the environmental degradation of pastoral systems in arid and semiarid regions of the world must be addressed. Individuals concerned about animal welfare and rights are now expressing their concerns about how food-producing animals are handled and managed. The relationships of agricultural and economic policy to the health of farm families, livestock, and the environment are now major concerns (Donham and Thu, 1993). Sustainable agriculture is now being emphasized. These issues and whether animals should be used at all for food production are discussed elsewhere in this book.

Animal Disease

Disease in farm livestock has always been a problem of considerable importance to farmers. Good livestock husbandry means caring for animals properly and maintaining them in good health to obtain optimum production of their products. As production methods become more intensive, the health status of animals becomes increasingly a primary determinant of productivity on livestock farms. The modern livestock producer attempts to maintain the performance of the herd or flock by proactive health and production management. The assistance of the veterinarian and of other agricultural specialists who can provide knowledge, skills, and other resources may be sought. The entire process is aimed at the production of wholesome human food, such as meat and milk, and of other commodities, such as wool at a reasonable price to the consumer, while yielding a net profit for the farmer.

The epidemic of foot-and-mouth disease in pigs, cattle, and sheep in the United Kingdom and continental Europe in February 2001 is an example of how one animal disease can be so devastating to the overall economy of a country and can create anxiety in other countries that fear introduction of the disease. The epidemic of foot-and-mouth disease in the United Kingdom in 2001 will be a major "watershed" event for food-animal production worldwide. Farming methods, the movement of animals, the intensification of animal agriculture, the identification of individual animals. international trade in livestock and animal products, and the methods used to control epidemics of animal disease will be examined closely. It may no longer be acceptable to slaughter hundreds of thousands of otherwise healthy animals as part of a foot-and-mouth disease eradication program compared with ring or mass vaccination even though vaccination may not be sufficiently efficacious.

Economics of Food Animal Production

The food animal industries are facing global competition and revolutionary changes (Meeker, 1999). Changes are occurring in agribusiness that are restructuring the livestock production industry. The primary factors responsible for these changes are capital and technology. The successful livestock producers in the future will use these factors to assemble *value chains* that are based on quality. (A value chain refers to the vertical cooperation among the participants in an industry.) Globalization of the competitive market place is reality. Communication technologies and free trade

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agreements between trading countries accelerates the process (BeVier and Lautner, 1994). As economies improve and discretionary incomes increase, meat production and consumption rise. The various protein sources compete for market share with cost of production as the major competitive factor. Progressive producers are becoming more aware of the needs of their consumers and are striving to improve product quality. Checkoff funds from producers (levies on each animal sold at market) are used to finance promotion, research, and consumer information programs and are increasingly used to finance producer education.

Industrialization trends in the livestock industries are changing the needs of constituencies, delivery mechanisms, and relationships with the people involved. Characteristics of nonprogressive livestock operations include high production cost, outdated technology, smaller size, older operators, and lack of management focus. Successful livestock operations tend to be growing in capacity, are system-oriented, maintain high throughput, keep accurate records, use outside consultants, and control production costs. Modern livestock production has lowered the cost of production with the integration of new production and management technologies. In order for producers to be successful in the future, access to technology, capital, and timely information will be critical.

Controversial Issues

Food animal production and the animal and veterinary sciences face a series of challenges that have become embroiled in controversy (Thompson, 1999). Controversial issues affecting animal agriculture are among the most critical challenges facing the livestock industry today. Like all of agriculture, livestock producers are commonly unfairly portrayed as polluters and as contributors to a decline in environmental quality.

Industrialization (or intensification) and vertical integration in poultry, dairy, and hog production have placed livestock producers into conflict with advocates for rural communities. A few well-researched books, such as *Pigs, profits, and rural communities* (Thu and Durrenberger, 1998), have been written about the advantages and disadvantages that industrialization of the swine industry has had on the environment and society. The modern intensified swine industry is frequently cited as evidence for the economic advantage of industrial agriculture, the wide availability of abundant food at extremely low cost to the consumers, and the superior productivity and efficiency of modern farmers. But does cheap food for the consumer outweigh problems created by industrialized forms of food production? As reasonable as it sounds, this approach ignores a fundamental component of industrial agriculture. An intrinsic feature of industrialized agriculture is the concentration of power over the production and distribution of precious resources. Industrial agriculture has survived and prospered for the last half century because certain sectors benefit.

Changes in dietary recommendations have changed the public's attitudes towards meat. Consumers want agribusiness to produce a safe, healthy, nutritious product while maintaining acceptable environmental practices in conjunction with humane treatment of animals. Experiments with animal cloning and genetic engineering have placed animal scientists on the front pages of the world's newspapers. The use of antimicrobials in animal agriculture is blamed, perhaps unfairly, for the increase in antimicrobial resistance in human medicine (Khachatourians, 1998). Animal welfare concerns attract much attention. Membership in organizations dedicated to the protection of animals has grown for two decades. Animal protection groups that once confined their interest to pet animals or animals used in biomedical research are placing more emphasis on the well being of agricultural animals. The use of biotechnology in agriculture has created considerable suspicion about the safety of food products. Animal science departments are responding to some of these issues, such as animal waste, animal welfare, and food safety in their teaching, research, and extension programs (Swanson, 1999).

Whereas farm income was once the most controversial issue in animal production, producers, animal scientists, and veterinarians now face complex risk issues that have overlapping constituencies. There is a need to develop a forum in which these contentious issues can be discussed responsibly (Thompson, 1999). Such a forum will provide opportunities for written and verbal exchange of views on the various aspects of contentious issues. Journals, conferences, seminars, workshops, and formal graduate training constitute the possible venues for such a forum. Animal scientists and veterinarians should give immediate attention to the broad social changes that are affecting animal agriculture and that have changed the requirements of scientific and professional ethics for researchers, livestock producers, and the animal production industry. In particular, debate should focus on the changed nature of risk and on the ethical and political implications of that change.

In addition to the general issues just mentioned, specific incidents occur that spark public outrage, causing major political decisions that have far-reaching short- and long-term economic effects on animal agriculture in certain countries (both nationally and internationally). An excellent example was the epidemic of bovine spongiform encephalopathy (BSE) that was recognized in cattle in the United Kingdom in 1986, causing major economic costs and international controversy about the safety of beef as a human food (Bruce et al, 1997). The disease is not of major economic significance to individual herds because of the low within-herd incidence. However, the national and international costs associated with detection and control procedures, the cost of compensation and disposal of affected animals, and the loss of export markets was extremely high (billions of dollars) and probably unprecedented in modern history. The occurrence of this disease has also led to a public questioning of the safety of cattle products as human food and a shift in the dietary habits of concerned people. The threat of the human disease caused a significant fall in beef consumption and prices. In response to market forces, the United Kingdom instituted a compulsory slaughter of at-risk but healthy cattle, with significant economic and social costs. Subacute spongiform encephalopathies occur in humans (Creutzfeldt-Jakob disease) and the occurrence of a new spongiform encephalopathy in cattle used for human food has caused considerable debate on the risk to human health. In recognition of this, beef products with risk for infectivity were banned for human consumption early in the outbreak, and the list was enlarged as further information on infectivity of by-products became known. The Phillips Inquiry into the emergence and identification of BSE and variant Creutzfeldt-Jakob disease (vCJD), and the action taken in response to it up to March 20, 1996, was handed to the Government on October 2, 2000 (Phillips, 2000). As a result of over 2 years of inquiry, the report comprises 16 volumes containing findings and conclusions. It is now accepted that the new vCJD in humans in the United Kingdom is directly linked to the epidemic of BSE that was first described in 1986.

Outbreaks of foodborne illness in humans now make headline news. Hamburger disease in humans from the consumption of inadequately cooked ground beef containing *Escherichia coli* 0157:H7 was first identified as a cause of disease in humans in 1982 in people who had eaten hamburgers prepared in fast-food outlets (Powell and Leiss, 1997). A 1993 outbreak in Tacoma, Washington, was associated with

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a particular chain of restaurants and involved 700 confirmed cases; 125 people had to be admitted to the hospital. Cattle, sheep, and deer have been identified as reservoirs of *E. coli* 0157:H7. The organism can be found as a normal inhabitant of the intestinal tracts of cattle, and during the slaughter process the surface of the beef carcass can become contaminated, which can lead to subsequent contamination of ground beef. By 1994 the U.S. Department of Agriculture (USDA) introduced a new test that could detect bacteria on meat. By 1996, the USDA and U.S. President Bill Clinton announced that, for the first time in 90 years of federal regulations, every slaughter plant would have to test its raw products for bacterial contamination using a Hazard Analysis Critical Control Points (HACCP) system. These food safety issues have led to the emergence of risk communication as an important aspect of health management in livestock production. In addition, *E. coli* 0157:H7 in ground beef is considered a food adulterant, and such contaminated meat must be withdrawn from the market and destroyed.

Risk identification, analysis, and *communication* are now major areas of interest in the food industry. Risk is the probability of harm in any given situation, and the probability is determined by two factors: the nature of a hazard and the extent of anyone's exposure to that hazard. The product of the two factors (hazards and exposures) adds to the overall risk. Risk communication is the process of exchanges about how best to assess and manage risks among scientists, regulatory agencies, public interest groups, and the general public (Powell and Leiss, 1997). Risk communication does not mean denying that a potential problem exists. The risk must be acknowledged and evaluated.

The work of risk communication occurs within that large gap that often separates two evaluations of risks: those of scientific experts on the one hand and those of members of the public on the other. Good risk communication practice seeks to bridge that gap by ensuring that the meaning of scientific risk assessments is presented in understandable terms to the public and, equally, by ensuring that the nature of the public's concerns is known by and respected by risk managers. Often there is little or no effort by either group, and a risk information vacuum interposes itself between experts and the public. Trapped in the resulting solitudes, experts bemoan the public's irrationality while being repaid with the public's contempt for their indifference and arrogance (Powell and Leiss, 1997). These solitudes represent risk communication failure.

Problems in communicating about risks originate primarily in the marked differences that exist between the two languages used to describe the experience with risks: the scientific and statistical language of experts on the one hand and the intuitively grounded language of the public on the other.

There is a need to narrow the gap between society's perception of the risk and what the risk really is, and what people can do to protect themselves. All of the players in the food chain, from producer to consumer, have a responsibility to recognize the importance of food safety and to use judicious and prudent methods to minimize the risks to human health.

Many opportunities exist during production, processing, distribution, retail, marketing, and consumption for pathogens to find their way into beef and beef products. Eliminating pathogens and therefore the risk of contracting a foodborne illness from beef products is a monumental, if not impossible, task. Therefore the approach must be *the exploration of methods of risk reduction rather than complete risk elimination.*

This book describes the role of the veterinarian in planned animal health and production in food-producing animals, particularly cattle, sheep, and swine. The major importance of poultry as a food-producing animal is recognized, but this book does not deal with poultry health and production.

A planned animal health and production management program, commonly known as herd health, is a combination of regularly scheduled veterinary activities and good herd management designed to achieve and maintain optimum animal health and production (Blood, 1979). Herd health programs vary from simple systems, in which the veterinarian visits the herd on a regular basis to examine animals and their performance and to make recommendations for the control of disease and improvement of production, to intensive programs, in which the veterinarian—with the assistance of other agricultural science specialists—makes detailed recommendations about the daily management of the animal health production program. This may include recommendations on nutrition, housing, genetic improvement, purchase of breeding stock, selling of animals ready for market, and cash flow.

Some veterinarians are now employed as resident herd managers and are responsible for ensuring maximum use of all available resources by coordinating the services and advice provided by all the agricultural advisors who are involved with the herd.

The terms *production-oriented medicine* and *performance medicine* are now being used to emphasize the importance of animal diseases and production problems that impair productivity rather than cause clinical disease. Of even greater importance in this context is the close relationship between animal health and production and the need to develop an integrated approach to production-oriented health management programs. *Herd health, preventive veterinary medicine, health management, health and production management,* and *production medicine* are expressions used synonymously throughout this book, and they generally refer to the same activities. An understanding of production medicine is essential if veterinarians are to have a role in the livestock production industries of the future (Guterbock, 1994).

OBJECTIVES OF HERD HEALTH MANAGEMENT

The primary objective of a health and production management program for herds of food-producing animals is the maintenance of animal health and production at the most efficient level that provides competitive economic returns to the animal owner. The ever-present goal is to control and manage animal health and production at a high level of efficiency while seeking and introducing new techniques that can continue to improve efficiency. Of major importance is that health and production management practices must document that they have a sound economic basis for success.

Some equally important secondary objectives include the provision of comfortable animal facilities and housing commensurate with reasonable animal welfare. Good animal production and animal welfare are complementary veterinary concerns. In addition, the minimization of pollution of the environment by animal wastes, the prevention of zoonoses (diseases transmissible from animals to humans), and the avoidance of contaminants and residues in animal products are all important considerations.

TARGETS OF ANIMAL HEALTH AND PRODUCTION PERFORMANCE

The objectives of herd health are achieved by the application of the concept of target of performance. *A target of performance is the level of animal health and production considered to be*

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optimum and to yield the best economic returns on investments. Targets of performance are determined from the performance found on a sample of farms considered to be representative of the economically conscious commercial farm population.

In a herd health management program, the actual levels of animal health and production are determined on a continual basis and compared with the targets of performance. The differences between the targets of performance and actual performance are the shortfalls in performance. The reasons for failure to achieve the targets of performance are then identified. Recommendations for improvement are made and performance is monitored continuously to assess the effectiveness of the action taken. These measures are then repeated on a continuous basis (Fig. 1-1).

HISTORICAL ASPECTS OF HEALTH MANAGEMENT OF FOOD PRODUCING ANIMALS

The historical development of health management of food-producing animals can be divided into four phases of activity (Table 1-1).

Phase 1

Phase 1 began about 100 years ago. National and state governments were involved in the eradication of diseases, such as brucellosis and tuberculosis, which were the causes of large economic loss and were transmissible from cattle to humans. By the end of the twentieth century, these diseases had already been eradicated in some countries, and real progress is currently being made toward eradication in others. Some countries have been involved in the control of contagious diseases, such as foot-and-mouth disease, rinderpest, and trypanosomiasis. These efforts were introduced to reduce livestock losses, which lead to widespread nutritional deficiencies among the human population. National disease eradication programs were directed toward effective control of diseases in the animal population on a geographical basis. As each area became free of the disease, only disease-free animals were allowed to enter. In this way, the disease theoretically could be eradicated from the entire country. These programs have been successful because the diagnostic tests were reliable, the testing was compulsory, and the financial resources necessary to do the job were made available from the public treasury.

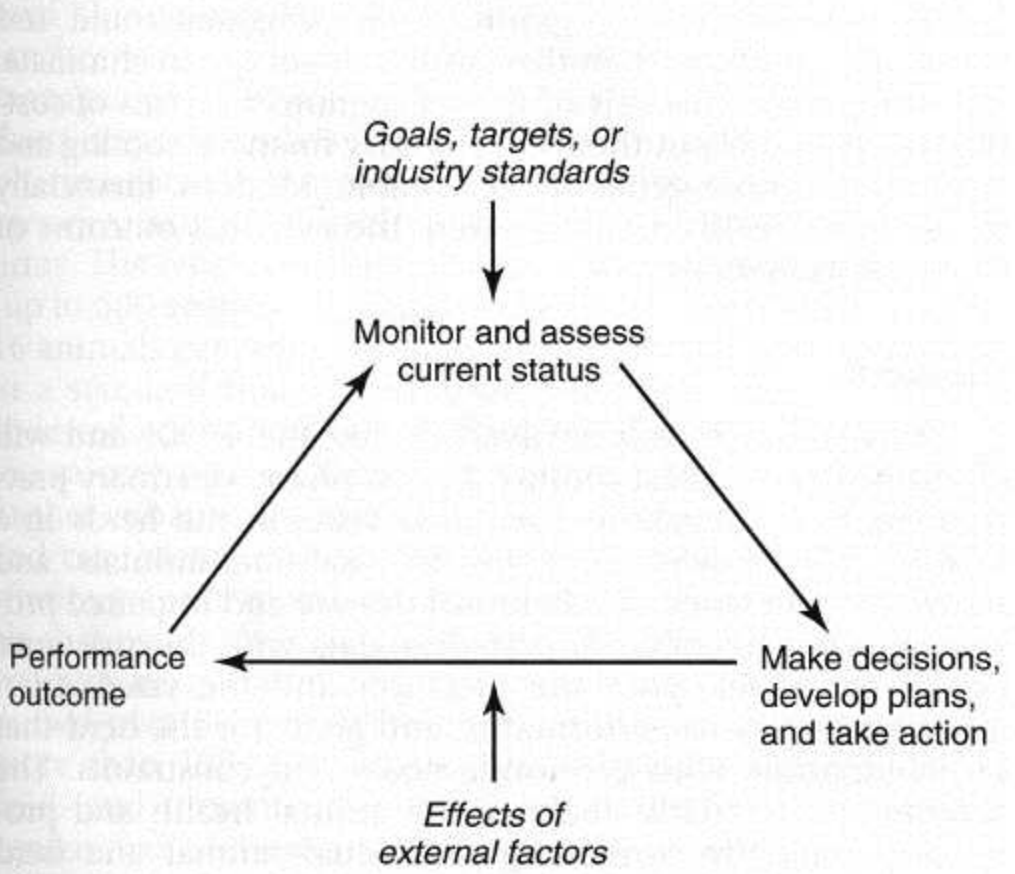

FIG. 1-1 Health management feedback cycle.

Phase 2

Phase 2 began around 1940 when meat-, milk-, and fiber-producing animals (cattle, swine, and sheep) became valuable as animal farms began to sell livestock and by-products off the farm as a source of net income. Before this time, most practicing veterinarians were involved in equine practice, which consisted largely of seasonal routine work. With the decline of the horse as a source of mechanical power on the farm, veterinarians turned their activities to cattle, swine, and sheep practice. Between 1945 and 1965, an exceptionally large growth occurred in rural large animal practice. This period coincided with a sharp increase in the standard of living in developed countries, which created an unprecedented demand for meat and milk. The law of supply and demand increased the price of meat to the consumer, and in turn farm animals became valuable. When animals became ill, it was economical to call the veterinarian to treat them on an individual basis.

Veterinary college clinical practices were developed in the "Phase 2" period. Veterinary graduates possessed the knowledge and skills to treat a wide variety of animal diseases successfully. Antimicrobials were also introduced, and veterinarians could treat many more of the common infectious diseases, such as pneumonia and enteritis, with spectacular results. Veterinary graduates were taught how to perform aseptic surgery. For example, the cesarean section became a common surgical procedure in bovine practice. This created a large demand for veterinarians and their services. However, because of a shortage of veterinarians, those who were in practice were busy and spent most of their time treating individual sick animals. This activity was referred to as *fire engine practice.* Because of a lack of time, little effort was made to control or prevent diseases or to manage health and production on a herd basis. The emphasis was on the individual animal affected with a clinical disease. Disease control efforts consisted mainly of large-scale testing and vaccination programs for diseases such as brucellosis. In North America, for example, veterinarians spent considerable time vaccinating pigs for hog cholera and cattle for brucellosis as part of national control and eradication programs.

Phase 3

Phase 3 developed around 1965 when both veterinarians and producers began to appreciate the value of being proactive in the maintenance of a high level of animal health and efficient production on a herd basis. Producers themselves gradually learned how to recognize and treat some of the common diseases of farm animals. In the earliest stages of this phase, preventive medicine consisted of recommendations for the control or prevention of specific diseases. For example, an outbreak of blackleg in young cattle was followed by a recommendation to vaccinate all susceptible animals with a clostridial vaccine. This was later followed by the veterinarian's recommendations for control of a number of specific diseases that were likely to occur in the herd. As veterinarians became more involved on a regular basis and more familiar with the herd and the producer, the presence of subclinical disease and inadequacies in management that caused poor animal performance was recognized. Subclinical disease in its broadest sense was recognized as the major cause of economic loss in food-producing animal herds. For example, diseases such as infertility and subclinical mastitis in dairy cows and intestinal helminthiasis in sheep responded dramatically and economically to strategic

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TABLE 1-1

Historical Development of Health Management Veterinary Services

Phase	Principal Preoccupation	Principal Mode of Action	Principal Agent	Support Mechanism
1	Area problems; protection of all herds by control of disease on area basis	Government-sponsored health programs on area basis; brucellosis and tuberculosis eradication programs	Government veterinary officer	Troubleshooter from government agency
2	Treatment of individual animals gives rise to inquiries about health management programs	Incidental preventive programs, (e.g., mastitis control, fertility, maintenance, parasitic disease status)	Private practitioner	Private, university, or government consultant
3	Positive action through herd programs to maintain health status, (e.g., reproductive efficiency, quarter infection rate)	Packaged herd disease preventive programs; planned actions at programmed visits	Private practitioner (or government or employed veterinarian)	Consultants (as above) with specialties in individual diseases
4	Integration of health maintenance plans with production and management plans to give whole-farm best effect	Positive action through herd programs (as above) with control data handling for all participating herds; data bank makes production planning and prediction possible	Private practitioner (or employed veterinarian); may be in conjunction with production advisor	Disease consultants and production advisors, but data laboratory most important for providing statistical and financial analysis

prophylactic procedures and changes in management. During this phase, the use of the word disease was expanded to include not only clinical and subclinical disease but also management inefficiency; all three can result in suboptimal performance (Blood, 1979).

The recognition that economic benefits could be derived by taking positive action against subclinical disease was followed by the development of planned herd health programs. Veterinarians began to make regularly scheduled visits to farms to examine the animal health and production status of the herd and to make recommendations for improvement. Herd health began to evolve. Between 1970 and 1980, there was considerable activity in the development of herd health programs for dairy cattle (Goodger and Ruppanner, 1982a). Considerable progress was made in dairy and swine health management. Programs for beef breeding herds and feedlots and for sheep flocks began to develop in a meaningful way. In 1983 a Canadian survey of food animal practitioners revealed that 80% indicated that some of their work was health management, with an overall average of about 30% of total time devoted to herd health activities (Magwood, 1983). In the 1980s considerable progress was made in the health management of dairy cattle, beef breeding herds, beef feedlots, swine herds, goat herds, and sheep flocks. During this phase farmers and veterinarians recognized the value of keeping good records of animal health and production so that an objective analysis of health and production, including the costs of production, could be made.

The inclination was to fill the program with every known preventive measure (e.g., whether the disease was likely to occur, whether a particular technique was highly effective), and often the program included more than one technique to prevent one disease. This was one of the false steps made in the early stages of this new expansion into herd and flock health management programs. Such programs could and often did cost more than the waste they set out to eliminate. The subsequent analysis of these programs in terms of cost-effectiveness has put them on sounder financial footing and made them more generally acceptable. Modern, financially viable herd health programs were the eventual outcome of this evolutionary process.

Phase 4

Phase 4 has mostly evolved during the 1990s and will continue into the 21st century. In this phase, veterinary practitioners make regularly scheduled visits to the herds in a health management program to examine animals and records for evidence of subclinical disease and impaired productivity and to collect and analyze data with the assistance of the computer. Both the producer and the veterinarian agree on targets of performance and goals for the herd that are compatible with economic goals and constraints. The veterinarian regularly analyzes the animal health and production data. By comparing individual animal and herd mean actual performance with the targets of performance, the component of the production cycle in which there is a

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shortfall is identified. Subsequently, the veterinarian attempts to determine the reasons for failure to achieve the desired targets of performance. With the assistance of agricultural advisors (nutritionists, geneticists, engineers, economists), the veterinarian can make recommendations for improvement in animal health and production. The ideal objective is to maximize the use of the resources available on the farm through the "whole-farm" approach (Howe, 1988).

Progressive food-producing animal veterinary practices of today and the future will be a multiple-person practice providing comprehensive health and production management veterinary service to livestock producers who are in the business of food animal production. The practice will provide a complete animal health management service, including consultative advice on treatment and control of disease, a complete record keeping system, and regular, even daily, animal health and production reports of the herd. Such veterinary practices will be staffed by species-oriented veterinarians with special expertise in some aspect of food animal production. Animal health data collection and analysis will be a major activity. In some practices with access to large numbers of animals, clinical research on the efficacy of drugs and vaccines will become a significant activity. Biostatistics and the preparation of research reports will become a major activity. Some veterinary practices will restrict their services to certain clients, such as beef feedlots, dairy herds, swine herds, or beef-breeding herds. Animal health technicians are now employed by these practices to assist in the treatment of animals, collection of laboratory samples for herd investigations, routine elective procedures, and collection of health and production data. Clearly, the emphasis will be on the health and production of healthy animals and getting paid for healthy animals rather than a fee for service for attending to sick animals. Thus the paradigm is shifting from emphasis on health and production rather than on the traditional role of the veterinarian as "a healer of the sick."

There are some examples of veterinary practices that represent an advanced stage of Phase 4. Feedlot Health Management Services (Okotoks, Alberta, Canada) is a consulting company providing comprehensive herd health programs, veterinary consulting services, and computerized health recording systems to feedlots and cow-calf herds throughout western Canada and the United States. The practice currently involves six veterinarians and twelve support staff. The practice has expanded over 20 years and, as of 2001, provides production consulting services to beef feedlots with an annual throughput of greater than 1 million animals and ranches with about 10,000 beef cows. In addition to health management services to their clients, the practice also conducts research studies in feedlot and cow-calf operations for pharmaceutical companies, feed companies, government agencies, academic institutions, and independent research firms. The feedlot studies are conducted in both large pens (up to 600 animals per pen) and traditional small pens (8 to 16 animals per pen). All studies are designed and conducted to a standard that would allow for publication in a peer-reviewed scientific journal. The objective of these studies is to evaluate new and existing technologies and products to further enhance the efficiency of production and the quality and consistency of the beef produced. The results of these studies are incorporated into computerized economic models that assess the overall cost-benefit of the technology or product in question. The practice has authored or coauthored over 30 peer-reviewed scientific articles, completed more than 100 technical reports relevant to the academic field, and presented technical material at more than 175 conferences and meetings throughout the world.

In Phase 4 resident veterinarians are becoming more common. Large dairy farms, for example, employ an experienced dairy cattle practitioner as a full-time employee to manage the health and production of the herd and other aspects of the farming operation. The veterinarian needs to have an advanced understanding of all aspects of dairy cattle health and production and must be able to integrate the services of nutritionists, building and ventilation engineers, geneticists, computer programmers, and animal health technicians and animal attendants.

It is now generally agreed that subclinical diseases or production inefficiencies, many of which cause no recognizable clinical signs, are the most important contributors to reduced productivity. These production inefficiencies, which are caused by factors that impair animal health, can be eliminated in the foreseeable future by three prerequisite inputs. Production can be improved if (1) current knowledge is applied, (2) animal health delivery systems are improved, and (3) new technology is developed through basic and applied research in areas where suitable measures are not presently available. Each farm presents a unique combination of factors contributing to suboptimum performances. In addition, each producer has a different attitude to change and risk (Caple et al, 1989). Agricultural extension services have helped to make major strides in improving the efficiency of livestock production. However, it is now apparent that the solution to improving suboptimal performance in the field is to have consultants and advisors work directly with the individual producer, who is charged for the services provided.

Major changes occurred in the 1980s and 1990s that have implications for animal production in the 21st century (Anderson and Pritchard, 1980). The development of a totally integrated animal health and production management system is the most important need, and this book describes the systems proposed. In 1982, it was predicted that epidemiologic surveillance would become the "core" activity of the public and private practice of preventive veterinary medicine (Schwabe, 1982). Epidemiology now provides a wide range of methods and knowledge that will assist the animal health challenges of the 21st century (Dorn, 1992; Meek, 1993). This is especially true for the interaction of veterinary epidemiology and agricultural economics.

Management decisions affecting animal health and productivity are increasing in complexity, regardless of whether they are made at a national, regional, or farm level. Decision-makers (whether administrators, veterinarians in clinical practice, or producers) need reliable, quantitative information about the health and productivity of the livestock in their care. Epidemiology contributes to health and productivity monitoring programs by asking three questions (Dohoo, 1993): What should be monitored? How should the required data be obtained and analyzed? How should the information be distributed?

Other Changes in Phase 4

Regulatory veterinary medicine has changed dramatically (Reid, 1992). In Canada, for example, the federal regulatory veterinarian has moved out of the role of a clinician diagnosing animal disease (tuberculosis and brucellosis) into the following roles: an epidemiologist tracing the movement of disease; a biochemist or toxicologist understanding the movement of chemicals through the animal body; a zoologist understanding many species; a manager supervising staff; an innovator coping with new and unusual situations; and a promoter selling the industry, the public, peers, and superiors on the value of health programs including food safety. Food inspection has expanded to include a major emphasis on monitoring programs that are able to detect pathogens and antimicrobial and other chemical residues.

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Biotechnology offers many new approaches to the management of disease and improvement of animal health. Recent advances in cell and molecular biology have led to development of recombinant DNA technology or genetic engineering. The DNA content of cells or organisms can be manipulated so that they produce greater quantities of a protein or, alternatively, a foreign protein. Genetic engineering has the potential to generate disease-resistant strains of animals. Biotechnology provides endless opportunities for veterinary medicine, including medicinal and pharmaceutical chemistry resulting in a wide range of therapeutically important compounds, nutrition, transgenic animals and plants, and new and more accurate and rapid diagnostic tests (Headon, 1994; Jackwood, 1994). Genetically engineered vaccines for animal viral diseases retain the advantages of live viral vaccines but overcome the safety hazards and logistic disadvantages inherent in live agent vaccines (Yilma, 1994). Major advances in the diagnosis and control of parasitic diseases are being made with biotechnology (Zarlenga, 1994). Although biotechnology offers many potential new approaches to management of disease and improvement of animal health, it is, however, an area that generates a high level of interest and controversy concerning moral and ethical values within the scientific and lay communities (McDermott, 1994). These value judgments must be considered and weighed for application in the research or commercial areas.

This book outlines the remarkable progress in the development of production-oriented animal health management veterinary services for food-producing animal production units. New technological developments now make it possible to improve the quality of diagnosis, treatment, and control of animal diseases, to enhance the quality of animal life, and to effectively chart the economic implications of such changes.

Herd Health and Production Programs in Developing Countries

In industrialized countries, herd health programs developed in response to structural changes in agricultural production. Among the major changes was the reduction in the number of farms but with increasing numbers of livestock per unit, increases in gross receipts, and vertical integration within industries. Owners of these evolving farming enterprises made demands on service providers, including veterinarians, nutritionists, extension specialists, and other disciplines, to provide more cost-effective services. At first, services offered to improve livestock health were not always accepted as appropriate or cost-effective. Therefore herd health programs in industrialized countries have evolved continually to meet the perceived needs of farmers and to keep in step with biological advances and computer technology.

In contrast, in developing countries, smallholders and less capitalized livestock producers do not have ready access to, and maybe have a lesser need for, herd health programs. Some attempts have been made to offer smallholders the essential elements of herd health and production programs. Smallholders in developing countries generally are not empowered to make demands on governments for herd health programs, and private sector services are not generally available. However, smallholders require better and more readily available livestock services, and herd health and production programs can be a framework to provide these services. The Food and Agricultural Organization (FAO) of the United Nations has a mandate to promote sound scientific, technological, social, and economic actions towards the conservation of natural resources and the adoption of improved methods of agricultural production (FAO, 1993). The first Expert Consultation on the application of effective herd health and production programs to increase livestock productivity in developing countries outlined technical, financial, and socioeconomic prerequisites for applying the herd health and production program approach. Concrete actions by Member Countries and FAO to further develop and implement this approach have been described (FAO, 1993). The summary and recommendations are shown in Box 1-1.

Changes in Society that Have Special Importance to Veterinary Medicine

Changes in the environment in which veterinary medicine functions and their implications to the veterinary profession have been described (Pritchard, 1993). The most important changes are the following:

- The changing status of animals and the increased importance placed on animals by society are enhancing the social and economical value of veterinary services.
- People increasingly seek veterinarians for advice and services on the care, husbandry, health and utility, and productivity of animals, not just for medical and surgical services.
- The public expects, and increasingly is willing to pay for, high-quality veterinary services for all kinds of animals.
- Far-reaching structural and technological changes are developing in agriculture, which are profoundly changing the kinds of animal health services required by the food animal production and processing industries.

Advances in science and technology, particularly at the molecular level, are revolutionizing the understanding of life processes and disease and their control as well as increasing the power and specificity of all kinds of veterinary technology. Spectacular advances in electronics and in information management through the use of computers have the potential of markedly improving the efficiency and effectiveness of veterinary practice (Dye et al, 1994; Wise, 1992). Veterinary tasks and functions in the public and private sectors are being altered by the growing involvement of many countries in the economic and political affairs of the world (Howard, 1992).

Structural Changes in the Veterinary Profession

Many of the preceding environmental changes have been occurring for a long time (Pritchard, 1993). Since the 1940s major change has occurred in the veterinary profession in the developed countries, and the profession has undergone a process of progressive differentiation, which is continuing. The profession used to consist of a body of individuals, each of whom was as capable as any other veterinarian—within the limit of personal ability—of conducting all of the tasks and functions required of the profession at that time. It is now composed of veterinarians with different skills who focus their professional efforts on a limited component of veterinary practice (e.g., small animal practice, large animal practice, feedlot practice, dairy cattle practice, swine practice). In 1992, 57% of practicing veterinarians in the United States identified their professional activity as exclusive small animal practice. Ten percent of practitioners were in large animal practice exclusively, and 62% of those further limited their professional activity to horses, cattle, or swine. Twenty-six percent more reported their professional activity to be limited predominantly to a class of animals. Thus 67% of this group identified their professional activity to be limited exclusively to a class of animals or a species, whereas 92% declared their activity to be exclusively or predominantly devoted to a class of animals or a species.

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BOX 1-1

Summary and Recommendations of the Food and Agricultural Organization (FAO)

Reducing the inefficiency in livestock production leads inevitably to reducing family welfare risks and increasing food security. These are fundamental goals of livestock raisers worldwide. These inefficiencies essentially steal from farmers and, in the aggregate, from nations. The thefts may be in the form of visible epidemic disease, invisible production losses or simply living with low productivity. Reducing or eliminating lost productivity—be it from infectious, noninfectious or production diseases—requires conscious, informed decisions by livestock owners. The herd health and production programme approach is the framework for making sound decisions, implementing actions, measuring the effects and devising future actions.

The first Expert Consultation on the Application of Effective Herd Health and Production Programmes to Increase Livestock Productivity in Developing Countries outlines technical, financial and socio-economic prerequisites for applying the herd health and production programme approach. Concrete actions by Member Countries and FAO to further develop and implement this approach are elaborated.

Bearing the above in mind, Member Governments should:

1. Improve the delivery of veterinary and animal husbandry services at the local level to increase food production efficiency, food security and sustainable agriculture production. The herd health and production programme approach is one means toward achieving these ends;
2. Continue to vigorously and consistently implement programmes to eradicate and/or control infectious and parasitic diseases in livestock. Uncontrolled infectious or parasitic diseases effectively negate investments made in genetic improvement, nutrition, control of production diseases, international trade and processing/adding value to livestock products;
3. Establish, as a matter of urgency, where it does not already exist, a consultation group for herd health and production programme management. This group should include interested persons within the government livestock services (animal health and animal production), the private sector service providers (veterinarians, nutritionists, lenders, processors, cooperatives, etc.), producers of livestock products, (and) veterinary and agricultural faculties and other interested parties (development banks, non-governmental organizations, professional associations). Each consultative group for herd health and production programmes should be capable of providing administrative, technical, publicity and organizational support for persons and groups with expertise in herd health and production programmes;
4. Recruit other interested national organizations and together focus initially on applying, developing and refining herd health and production programme methods in local areas as a pilot programme. Locally focused pilot projects can be implemented within ongoing programmes or projects. Experience and lessons gained should then direct institutional changes, for instance, in university curricula, bank lending packages, cooperative services, continuing education, etc;
5. Secure, along with interest groups, FAO and other international development agencies, Trust Funds or alternative financing to establish the required infrastructure to implement pilot projects which develop the herd health and production programme approach in local areas;

FAO SHOULD:

6. Continue to articulate and promote the herd health and production programme approach aimed at enhancing livestock productivity, food security and sustainable agriculture production. Lessons learned indicate that for effective programmes to be adopted, livestock owners need to be empowered to take the lead in demanding effective services from providers, both government and private;
7. Articulate and promote the herd health and production programme approach using the protocol developed during the Expert Consultation which consists of the following elements:
   a. Agree with the management upon proposed production and risk reduction targets;
   b. Define and develop the tools and technologies required to collect the necessary data;
   c. Interpret the data gathered from all sources into information (usable knowledge);
   d. Develop and agree upon a plan of action which includes concrete steps to reach the production and risk reduction targets set in step 1; and
   e. Monitor and evaluate progress then begin again at step 1;
8. Identify and implement pilot projects based on the herd health and production programme approach among various livestock production systems. One medium-term goal of pilot projects should be to identify, document and recommend specific activities and within herd health and production programmes which are profitable for veterinarians to offer and financially advantageous for livestock owners to purchase;
9. Promote livestock product processing techniques, and encourage livestock owners to adopt such techniques, which add value to primary products and thereby increase farmers' purchasing power and food security. Adding value to livestock products is an adjunct to sustainable financing of herd health and production programmes;
10. Focus on explaining and sensitizing veterinarians and paraprofessionals already working in the field to the benefits of herd health and production programmes. Undertake studies on viable methods to finance sustainable delivery of herd health and production programmes at the farm/village level in different livestock production systems. Such studies might evaluate alternative financing (as discussed in the text), the need for initial subsidization, how long subsidization might be required, financing alternatives in livestock systems with periodic cash flow (nomadic pastoralists, transhumants) and the public versus private goods to be derived from herd health and production programmes;
11. Review the usefulness of current data collections systems with the view to collect and dispatch appropriate data to the appropriate organizational level. The criteria for "appropriate organizational level" should be that once data are received, this organizational level is in a position to act effectively on information derived from the data;
12. Encourage (sensitize) faculties to evaluate the role that the herd health and production programme approach

Continued

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BOX 1-1—cont'd

Summary and Recommendations of the Food and Agricultural Organization (FAO)—cont'd

might play in a revised curriculum for veterinary or auxiliary students;

13. Emphasize to Member Countries that the focus of the herd health and production programme approach is at the farm/village level. Therefore, training, institutional support, and data/information systems need to be designed from the bottom up assuring that the interests of local providers and livestock owners are best served;
14. Interest donors, the private sector, communities and others to finance pilot projects which develop and use the herd health and production programme approach;
15. Commission studies on and promote the use of standardized formula for production indices used by computer software developers and others when deriving livestock production information. Standardized production indices are essential requirements for consistent comparison of performance within and between livestock systems; and
16. Along with Member Countries, organize in-service training in the application of herd health and production programme approach for field staff at the local level using the most competent field personnel.

Text from Food and Agricultural Organization of the United Nations: Report of the Expert Consultation on the application of effective herd health and production programmes to increase livestock productivity in developing countries, Rome, Italy, March 30-April 1, 1993.

The proportion of veterinarians who provide services to more than one class of animals is diminishing progressively. In 1962, 66% of veterinary practitioners indicated that their professional activity involved more than one class of animals (that is, any form of mixed practice). In 1992 this figure had decreased to 33%. If all categories of professional activity are considered, this figure falls to 25%. In 2000, 70% of veterinary practitioners identified their professional activity as small animal practice (combined predominant and exclusive), 4% in equine practice, 12.8% in large animal practice (combined predominant and exclusive), and 7.6% in mixed animal practice (American Veterinary Medical Association [AVMA], 2000). However, the total number of veterinarians in large and mixed animal practice has increased slightly.

Differentiation in veterinary practice has been driven by three major forces: the growing body of knowledge about biology, health, disease, husbandry, utility, and productivity of animals and the increasing complexity of all kinds of professional activity; increasing expectations of animal owners as to quality of services delivered and the competency expected of all veterinarians in all sectors of the profession; and the desire of veterinarians to provide high-quality services for all animals. Differentiation in veterinary practice is unlike disciplinary specialization in human medicine but is growing in veterinary medicine. Veterinarians who focus their efforts on a class of animals provide primary health care of a general nature to that class of animals. This is in contrast to human medical specialists (e.g., dermatologists, internists, cardiologists, neurologists) who provide a secondary level of service, limited to a defined specialty, following referral from a general practitioner. A growing number of veterinary specialists are entering private practice.

A major change in veterinary practice evolving from differentiation is a change in the focus from individual animals to populations in most practice themes. For all classes of animals and all practice themes, except for companion animals, a population approach to problem solving and health management is the major activity, with concern for individual animals being of lesser or no importance. To prepare the profession for the tasks of the future, a greater focus on populations and population approaches to health and disease will be needed. This will necessitate the expansion of instruction in epidemiology and population health and medicine in veterinary curricula.

The need to move toward more instruction on population-based health and medicine is being recognized by veterinary colleges and courses in biomedical statistics, quantitative epidemiology, veterinary economics, and herd health and production management. Improving instruction in population health and production is a more difficult task than restructuring the curriculum to accommodate electives or tracking, which is the traditional way that veterinary medical colleges have responded to the increasing complexity of veterinary practice. A population approach requires new and different ways of thinking about health and disease, diagnostic approaches, and strategies for solving health and production problems.

The profession must radically rethink the undergraduate curriculum if it is to prepare graduates adequately for the 21st century (Halliwell, 1999). It has been suggested that if the profession does not act resolutely, with vision and boldness, it will dissipate much of its potential to serve the future needs of society (Nielsen, 1997, 1999). Designated licensure and speciation within the veterinary degree would provide veterinary students with the flexibility to pursue their areas of interest and to be much more competent at graduation than the veterinary student who has attempted to learn all aspects of veterinary medicine (Karg, 2000). (Speciation as used here means to identify a change from uniform licensing across taxonomic barriers to designation for a limited number of species.) The organized veterinary profession, not the universities, has the instruments necessary for leadership in making sure that society's needs are met, namely through veterinary licensure, regulation of internships, setting practice standards, and college accreditation. In a tracking system of education, veterinary students would have to choose one of several major career paths, such as mixed practice, small animal practice, equine practice, food animal practice, public health, food safety, comparative medicine, zoo medicine, aquaculture, or ecosystem health (wildlife) at the end of second year of a 4-year professional course. Examination for licensure would be tailored to the career path chosen (Nielsen, 1999). The effects of this approach

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would be to require students to make career choices earlier in their undergraduate veterinary program, increasing the standards of competence at graduation to more effectively meet the needs of society (Nielsen, 1997). The lack of mandatory clinical internship in veterinary medicine, as exists in human medicine, means that the undergraduate clinical education program must be as comprehensive as reasonably possible to provide the graduate veterinarian with the knowledge and skills necessary to meet the needs of the public. A veterinary graduate who becomes competent in a particular sector of veterinary medicine before graduation does not have to learn the basic clinical skills at the expense of the unsuspecting public.

It no longer makes sense for the profession to cling to an inaccurate and outdated view of the capacity of the veterinarian. The time when an individual veterinarian could reasonably be expected to possess the needed skill and knowledge to care for the health needs of all kinds of animals at a level acceptable to the public is long gone. It is an important part of the profession's history, but has no validity now and will certainly not be valid in the 21st century. It is important to recognize this reality for it accepts many things that the profession does. The concept of the universal veterinarian is an anachronism, and it should be buried with honor. The impossible dream—the DVM who can provide the health of all "creatures great and small" is inhibiting the progress of the profession. It is at the very root of serious problems facing veterinary educational issues today. (Pritchard, 1989a)

Economic Status of Veterinary Profession

An analysis of the current and future market for veterinarians and veterinary medical services in the United States identified six critical issues, all of which must be addressed successfully to improve the economic health of the profession (Brown and Silverman, 1999).

- *Veterinarians' income.* The income of individual veterinarians is much lower than that of similar professions, which may affect recruitment of highly qualified and intelligent students to the profession.
- *Economic consequences of a large percentage of women in the profession.* There is evidence that the income of female veterinarians is far below that of their male colleagues, that female veterinarians work fewer hours and are less likely to become practice owners, and that they may price their services below that of male veterinarians, thus reducing the income levels of all veterinarians. Between 1990 and 1995 the net increase in the number of female veterinarians was 9.5 times greater than that in male veterinarians (Gehrke, 1996); and the number of female veterinarians will equal the number of male veterinarians by 2004.
- *Global demand for all categories of veterinary services.* There is substantial opportunity to increase demand for veterinary services.
- *Inefficiency of the delivery system.* The majority of animal care is still delivered through a highly fragmented and inefficient system.
- *Supply of veterinarians.* On economic terms, Gehrke (1996) suggested that there is an excess of veterinarians in the United States, which is a cause of low veterinary income. More important, the characteristics of the supply of veterinarians do not closely match the demand, and there is evidence that modifications in the education of veterinarians will enable the profession to capitalize on emerging markets and to create new services.
- *Skills, knowledge, aptitude, and attitude of veterinarians and veterinary students.* Although the scientific and clinical skills of the profession are high, there is evidence that veterinarians lack some of the skills and aptitudes that result in economic success. Also, the perception veterinarians have of their abilities and what they can contribute to society potentially limits the professional and economic growth of the veterinary profession.

Economic Transition in Veterinary Medicine

The economic status of the veterinary profession in the United States has been examined from the perspective of an agricultural economist (Getz, 1997). The study suggests that veterinarians are in excess supply and that the excess will probably increase throughout the current decade. Evidence indicates that the population of veterinarians continues to expand rapidly. Eighty percent of the veterinarians who reported their employment are in private practice; 20% are salaried employees of industry, government, and academia. Among the veterinarians in private practice, 75% work exclusively or predominantly with small animals. Another 4% are in equine practice, and 8% are in mixed practice providing service to both large and small animals in approximately equal quantity. Only 16% of the private practitioners worked predominantly or exclusively with large animals. Thus only 16% of private practitioners served primarily agriculture. The number of animals is changing. Among companion animals, owners of dogs, cats, and horses make significant demands on veterinary services. With rising incomes more households are willing to spend more per pet on veterinary services, reflecting the closer personal relationships owners have with their pets. The number of families with pets continues to grow, thus explaining the overall continued growth of small animal practice.

The demand for numbers of veterinarians in agriculture appears to be stable or declining. Farms are becoming larger, and more livestock is grown on production contracts. With increased scale, fewer farms are needed to support a large animal veterinary practice, and large farms spend much less per animal on veterinary services. Many livestock operators work on long-term contract with processing corporations. Corporate farming enterprises are becoming large enough to keep a veterinarian on salary rather than relying on the fee-for-service veterinarian. When veterinarians are used more intensively, the aggregate demand for veterinarians declines. Ironically, agriculture may then be reducing its demand for veterinarians more than is indicated by the simple relationship with the stocks of animals being raised for production.

Within the last decade (1990 to 2000) there has been a growing shortage of food animal veterinarians in the United States who are knowledgeable and skilled to provide profitable health management services to livestock farms. This situation partly reflects current demographics, which indicates that farm population as a percentage of total population is only about 2%. Thus the primary pool of potential veterinary students with a significant and meaningful food-producing animal background, and who would be most likely to pursue a career in food animal practice, is relatively small.

The demand in food animal practice will be for veterinarians who are species specialists and can provide a comprehensive economically-based health and production management veterinary service. That is the challenge.

Veterinary Informatics

Practitioners are overwhelmed with new facts, new data, and new opinions. As well as the difficulties involved in keeping pace with the volume of new information, veterinarians are finding it more and more difficult to extract the kernels of

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"medical knowledge" from the growing mass of "medical information." Clinical research is described ever more in terms of often unfamiliar mathematical or computer models, and research results are in varied formats (Bellamy, 1999). This combination of problems is leading to delays in the application of the newest medical knowledge to veterinary problems. How should practitioners organize and communicate medical information so that the best new knowledge is readily available and can be applied rationally to veterinary problems? How can they revise or replace the organizational processes that force many medical decisions to be arbitrary rather than the best available? How do they maximize the benefits of veterinary research for veterinary practice and minimize the time and resources to achieve these benefits? Veterinary informatics is the study of how veterinary medical information is created, managed, communicated, and applied as knowledge to allow effective and efficient decisions to be made. Veterinary informatics encompasses veterinary information in all its forms, including words (text), numbers, mathematical models, and images (radiographic, microscopic). It examines how veterinary information is organized, classified, represented, stored, and retrieved for use. A central idea in veterinary informatics is the relationship between "information" and "knowledge"; how can information be transformed into useable knowledge that can be applied with confidence directly to making veterinary medical decisions? The computer is the main instrument of informatics. The computer is becoming as essential as the stethoscope, x-ray machine, or electron microscope to good veterinary practice and veterinary research. New computer technologies, combined with new information management and analytical tools, now provide veterinary medicine with the means to address its information challenge.

Veterinary information is the fundamental commodity of veterinary medicine; veterinary informatics is the study of how best to use this commodity. It is time to consider incorporating courses on veterinary informatics into the veterinary curriculum, providing sessions on veterinary informatics in professional development programs, and developing graduate programs in veterinary informatics to educate veterinarians and train specialists in this important emerging field. A major innovation in the delivery of the veterinary curriculum is being implemented at one veterinary college (Whithear et al, 1994). Students receive course information as interactive, multimedia databases consisting of text and an associated library of catalogued digital images, movies, and sounds. The new delivery method encourages greater autonomy and more interactive learning roles for students than occurs in traditionally taught courses. Students use their databases as the principal resource of information for undergraduate studies. A unique feature of this system is that students can modify and expand their databases during the course. The ultimate aim is for students at graduation to receive, on disc, a copy of their own databases, adapted by themselves to their particular future professional needs.

Modern telecommunications and information technology now provide unlimited opportunities for veterinary practitioners to access information through the use of desktop computers in their veterinary practice locations. The technology is now available to obtain full-length scientific journal publications over the Internet. The Internet provides an incredible amount of information on health and production of all animals. Where this will take us in the future is unknown. Certainly the amount of information now available is too much for any one person to assimilate on any one topic. It remains to be seen how we will learn to access and use this information effectively and efficiently.

CURRENT STATUS OF HERD HEALTH PROGRAMS AND THE MARKET FOR FOOD ANIMAL VETERINARY MEDICAL SERVICES

Veterinarians provide varying levels of planned animal health and production management services to dairy herds, beef cattle herds, beef feedlots, swine herds, goat herds, and sheep flocks. For daily herds with 50 to 150 cows, monthly visits are common. A smaller percentage of herds are much larger and may have up to 3000 or more cows. In these cases weekly or daily visits may be necessary. Swine herds are now very large and may have several hundred or thousand sows requiring that the veterinarian make weekly visits. Most beef breeding herds in North America are under 100 cows, and four herd health visits annually are usual. Feedlot veterinary medicine is now well advanced, and some veterinarians visit the producer's feedlots on a daily basis or at least once a week. Some feedlot veterinarians devote their entire practice to a few feedlots. Sheep-flock health and management services are now much more common. Goat producers are also requesting health and production services. There are many opportunities for veterinarians to deliver production-oriented health management services to the food-producing animal industries, which are looking to the veterinary profession for assistance. Multiple-person veterinary practices are becoming more common; these allow individual veterinarians the opportunity to develop a specialty in one of the food animal species.

Market for Food Animal Veterinary Services in the United States

The market for food animal veterinary services in the United States was surveyed by the AVMA in 1985 and 1994. In 1985 a national survey of livestock producers was conducted to obtain information on expenditures on veterinary medical service and animal health supplies, the characteristics of producers relative to their use of veterinary services and products, and the producer's perception about the knowledge, skills, and cost-effectiveness of food animal veterinarians and other suppliers of animal health information (Wise, 1987a,b, 1988a). Also, a national survey of food animal veterinarians provided data on veterinary medical service and product revenues. The perceptions that veterinarians have of food animal practitioners, livestock products, and alternative suppliers of animal health products were evaluated. The preparedness of recent veterinary graduates was explored. Finally, the survey was designed to investigate which areas of food animal practice are believed to represent the greatest and the least potential for future food animal practice growth (Wise, 1987a,b).

The findings were as follows:

1. In 1985, the total U.S. market for food animal veterinary professional services and products was estimated to be about 47% of the total agricultural retail market for animal health products and services. Of food animal veterinary revenues, the dairy market was the largest and accounted for 47%, beef cattle for 34%, swine for 15%, and sheep for 4% of the total. Professional services accounted for 62%; veterinary products accounted for 38%. At the retail level, 24% of the total livestock market for veterinary pharmaceuticals and biological agents, with the exception of feed additives, was through veterinarians, and 76% was through the over-the-counter market. Based on manufacturers' prices, 9% of the total livestock market for pharmaceuticals, biological agents, and feed additives was through veterinarians and 91% through over-the-counter channels (Wise, 1987a,b).

2. Approximately 73% of all livestock producers used a veterinarian either for professional services or for the purchase of animal health products. Food animal veterinarians

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were used annually by dairy producers about 20 times, by beef producers about 4 times, and by sheep and swine producers about 5 times. Larger livestock farms and ranches spent proportionately more money on animal health products and less money on animal health services than did smaller operations. In addition, larger livestock operations spent proportionately less of their animal health dollar with the veterinarian than did smaller livestock operations. For the analysis, operations were categorized according to three herd sizes: 1 to 49, 50 to 99, and 100 or more head. The amounts of money referred to above are total amounts for large and small farms annually; the amounts on a per-animal basis could not be determined from the data available (Wise, 1988b,c).

3. Livestock producers perceived food animal practitioners as knowledgeable and skillful in the diagnosis and treatment of sick and injured animals and in the clinical aspects of reproductive performance and breeding relative to their own knowledge and that of other suppliers of animal health information. However, producers perceived that food animal veterinarians possess about the same level of knowledge about animal and herd management, feeds, and nutritional management as they do themselves and slightly less than the feed company representative. Producers also perceived that the practitioner's knowledge of agribusiness and economics is weak relative to that of producers and agricultural extension agents.

4. The perception that the producer has of the veterinarian's knowledge and cost-effectiveness relative to other sources of information are significant determinants of who the producer first contacts for assistance. At least 7 out of 10 producers would contact a veterinarian first for the diagnosis and treatment of a sick or injured animal, 5 out of 10 would contact a veterinarian first for a reproduction problem, and about 3 out of 10 would contact a veterinarian first for a herd management problem. Only 1 out of 10 would contact a veterinarian first for a question on feeding and nutrition.

5. Most producers consider that veterinarians are important to their operation for diagnosis and treatment. About half thought that veterinarians are important for drug purchases, regulatory testing, and advice on herd health and reproductive problems. However, only about 15% considered veterinarians as important for feeding and nutrition problems. Nine out of ten producers thought that veterinarians are good at explaining what they know and are good listeners.

The suggested implications of the findings are as follows:

1. There is a need for food animal practitioners to document the cost-effectiveness of veterinary medical services for the business of livestock management and production. Although food animal practitioners are considered knowledgeable and effective communicators, they must demonstrate to producers that production-oriented health management services can enhance the revenue and profitability of the livestock enterprise.

2. The challenge for the future is to determine what veterinary services are needed by livestock producers and how veterinarians can deliver those services economically. Whereas veterinarians are highly regarded for their diagnostic and therapeutic skills, they are perceived to be inadequate in herd management, nutrition, and farm economics.

3. In the face of growing economic pressures on livestock farms, many veterinarians believe that the diagnosis and treatment of sick animals represents the least potential for long-term growth in food animal practice.

4. Long-term growth in food animal practice can occur most likely by a large shift in the practitioner's ability to help the producer make decisions about the animal health and production of the entire herd operation by using the whole-farm approach. This means the incorporation of the production and profitability goals of the producer, a ranking of animal health and production problems, and the implementation (along with the simultaneous measurement and assessment) of health management techniques to improve the efficiency and profitability of livestock production.

5. A fundamental task for the veterinarian is to shift from a fee-for-service or task-oriented business relationship to a fee-for-advice or information-oriented business relationship that focuses on the financial performance of the farm.

6. The food animal veterinarian is the logical professional person to deliver and coordinate advice obtained from other sources.

7. The failure of veterinarians to move quickly and more widely into an information-based animal health and production management service is partly due to the absence of appropriate information in their veterinary education. The fundamentals of whole-herd, information-based health management must include expertise in herd management, production analysis, nutrition, environmental analysis, epidemiology, agribusiness, communication, and the use of computers. Most of these subjects or skills are precisely the elements of a veterinary education that have traditionally been given the least attention, and veterinarians surveyed also thought that these are their weakest areas.

8. If veterinarians can improve their knowledge and skills in nutrition, herd management and reproduction, and farm economics, they increase the likelihood that producers will contact them first for animal health and production problems.

9. The feasibility of improving the veterinarian's knowledge and cost-effectiveness relative to other suppliers of information depends on or is related to the veterinary curriculum, postgraduate continuing education programs, and marketing. From a marketing perspective, there is a need for research into how producers' perceptions are formed and how they can be changed, by how much, and at what cost. From a veterinary education perspective, veterinary medical associations and colleges must collaborate to develop educational strategies for improving opportunities for established food animal practitioners to study in those areas that can meet the needs of producers. Veterinary colleges must incorporate educational experiences in the curriculum to enhance the knowledge, skills, and confidence of the new graduate. The food animal curriculum must be intellectually stimulating and interesting to the undergraduate veterinary student if the profession expects the necessary number of graduates to enter food animal practice. Role models are needed for these students.

10. Further investigation is needed to quantify and assess veterinary medical information as an input into livestock enterprises and to measure its cost-effectiveness. Animal health and production databases need to be developed through the use of practical systems of surveillance that can be incorporated into monitoring and problem-solving models for livestock producers and veterinarians. This can best be done by cooperative efforts among universities, participating livestock farms, food animal practitioners, pharmaceutical and biologic agent suppliers, diagnostic laboratories, and production recording services.

11. There should be additional investigations into the health management needs of producers. Also, the association between the characteristics and attitudes of producers and their use of veterinarians should be studied.

12. A need exists for more effective methods of reporting on the use and purchase of drugs and veterinary services by producers. There is little reliable and useful information about producers' expenditures on veterinary services and

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animal health supplies and about how much is spent on the diagnosis and treatment of sick animals compared with the cost of health management services.

13. The status of food animal practices should be reviewed and assessed periodically to determine how changes in the livestock industry can influence what changes need to occur in the delivery of food animal veterinary services. Veterinarians need to learn how to assess local livestock conditions and trends and to implement economical animal health marketing programs to meet the needs of producers.

14. Veterinarians must learn how to develop and implement practical strategies and specific client communication techniques so that their animal health and production services and information are used profitably by the livestock community.

The U.S. Livestock Market for Veterinary Medical Services and Products (1995)

In 1994, the American Veterinary Medical Association (AVMA) commissioned the Center for Information Management to conduct a study of the livestock market for veterinary medical services (Wise, 1995). The summary is as follows:

- The structure of agriculture is changing. The number of farms and ranches has been declining since the 1920s.
- Four forces strongly influence changes in the structure of animal agriculture: industrialization, globalization, food safety linkages, and consumerism. These are all areas in which veterinarians' training and knowledge can be applied specifically. The need for veterinarians' knowledge and skills in these areas is demonstrated by the AVMA's adoption of research priorities. Food safety for all Americans; food animal well being; new and reemerging diseases of livestock; quality food from animals for a global market; and environmental quality and agriculture, among others, were adopted as 1995 to 1996 research priorities.
- In 1987, Wise (1987a) concluded that "the fundamental task for food animal veterinarians is to shift from a fee-for-service or task oriented business relationship to a fee-for-advice or information oriented business relationship that is focused on the financial performance of the livestock enterprise." This conclusion is even more relevant today than it was 14 years ago. Task-oriented, fee-for-service, or fee-for-product relationships infer multiple market transactions. That is, each time a production facility requires veterinary services or purchases animal health products, a new transaction takes place. Globalization, food safety linkages, and consumerism have, through increased competition and regulation, increased the costs inherent in these multiple market transactions.
- Industrialization of animal agriculture infers a shift from multiple market transactions with their high costs to more coordinated relationships between producers and veterinarians. These more-coordinated vertical relationships—contracting and integration, to name two—are based on a constant flow of information, services, and products between veterinarians and livestock producers. Market transactions based on individual tasks, products, or services are reduced or eliminated. The transaction is based on the delivery of a complete animal health system. However, industrialization is most evident in only one segment of animal agriculture.
- Animal agriculture is diverging into two separate segments. The first segment is characterized by small, diversified production units. Livestock production is a result of crop production or off-farm work as the household's primary income source. These operations acquire animal health services through multiple market transactions. They have high per-animal health care costs and represent a limited percentage of all animal units in the United States. The demand characteristics of these clients more closely resemble those of companion animal clients rather than their large livestock counterparts.
- The second segment is characterized by large, specialized production units. The use of vertical coordinating systems is a common practice in these operations. The managers of these operations are continually searching for more efficient animal-health delivery systems, including service contracts with local veterinarians. The largest operations may even integrate animal health services by employing staff veterinarians. Data presented in the report indicate that these operations produce most of the animal units in the United States and have the lowest health care costs per animal.
- Expenditures per animal decreased significantly as herd size increased. This infers that large herds generate less animal health revenue for animal health providers than do small herds for a given number of animals. Data also revealed long-term trends that the numbers of beef cows, dairy cows, and breeding swine would continue to decline into the next century. When combined, these factors suggest downward pressure on the total U.S. market for veterinary medical products and services.
- Offsetting this trend was a significant increase in the per-animal expenditures for animal health services and products between 1985 and 1993. All prices paid by farmers increased by approximately 15% during this time. However, per-animal expenditures with veterinarians increased by more than 50%. If it is assumed that the prices of veterinary products and services increased at the same rate as all prices paid by farmers, the implication is a real increase of more than 35% in per-animal expenditures with veterinarians. That is, livestock producers used more services and purchased more or improved products from veterinarians.
- Expenditure and revenue data also suggest that products dominate the total animal health budget of livestock production operations. A significant portion of product expenditures was made with suppliers other than veterinarians. With the exception of swine practitioners, veterinarians' revenue data indicate that 40% or less of each veterinarian's individual revenue was from product sales. Interestingly, swine veterinarians produce the highest individual revenue and have the highest percentage of revenue from product sales.
- The results just mentioned, combined with a fee-for-information, vertically coordinated orientation, infers that veterinarians must include products as an integral part of the total animal health package that they provide. However, veterinarians should concentrate on providing the knowledge, not the products. This infers that products provided as part of the package must be competitive with products provided by outside suppliers. Veterinarians should concentrate on providing a knowledge-based package of animal health services and products because this is the area in which they have a competitive advantage.
- Producers consider veterinarians very knowledgeable and highly cost-effective problem solvers in areas concerning livestock production. Veterinarians are the most highly regarded individuals concerning reproduction, diagnostics, and treatment of disease and injury. They are producers' primary outside contact in these areas when problems arise. Producers generally consider veterinarians as knowledgeable as themselves and other individuals concerning animal and herd management, feed and nutrition, and agribusiness and economics. However, producers often rely on other sources of information in these areas, especially concerning agribusiness and economic problems.

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■ Despite producers' high regard for the knowledge and cost effectiveness of veterinarians concerning reproduction, diagnostics, and treatment, they rated local veterinarians' knowledge and cost effectiveness slightly lower in 1994 than in 1985. These results do not infer that veterinarians are less knowledgeable and cost effective, but it does suggest that producers perceive them to be so. This is important because perception drives demand.

■ Veterinarians have the knowledge and skills to influence the perceptions of producers. First, producers generally rate veterinarians as good communicators. Second, veterinarians are generally producers' first choice for an information source concerning problems in reproduction, diagnosis, and treatment.

■ If the business relationship between veterinarians and producers is a task- or product-oriented market relationship, the major objective of the transaction becomes the provision of the task or product. The task or product becomes the focus of the relationship, between the veterinarian and client. The knowledge of the veterinarian and the cost effectiveness of animal health services provided become secondary attributes. When the task or product is the objective, price is the motivator and the lowest price will prevail.

■ When the business relationship between veterinarians and producers is an information-oriented coordinated relationship, the major objective becomes the cost-effective application of animal health services based on the veterinarians' knowledge and skills. The tasks and products themselves become secondary attributes. Consequently, when cost-effective animal health service is the objective, profitability rather than price is the motivator. Therefore any price that fairly distributes the benefits of animal health services between the producer and the veterinarian prevails.

■ The difference between these two structures is not as much operational as they are attitudinal. Therefore the change is more of an educational process than a structural process. Livestock practitioners possess a vast amount of knowledge, many skills and abilities, and the goodwill and respect of their clients. However, knowledge, skills, and respect become secondary attributes to price when cutting costs is the motivation before profitability. Veterinarians need to be educators in this process.

■ Farms and ranches exist on a continuum, and the differences between the extremes may be distinct and identifiable. However, many operations exist somewhere between the extremes and are continually evolving.

■ Livestock veterinarians require a mixture of skills beyond diagnostic and treatment abilities to remain viable practitioners. Veterinarians require skills that will enable them to identify at what point on the continuum their clients and potential clients are operating and how they are evolving. These skills are required because the techniques for serving clients will vary and be dependent on these factors. Such a strategy will allow livestock veterinarians to realize the greatest potential demand for veterinary medical services and products.

In summary, the implications for veterinary medicine are as follows:

■ Four major forces affect structural transformation in food animal agriculture: industrialization, globalization, consumerism, and food and environmental safety.

■ Food animal agriculture is diverging into two distinct markets: One market is characterized by large specialized animal production units in which livestock production is the operators' primary occupation and source of income. The second is characterized by small, less specialized animal production units. Food animal production may be ancillary to crop production, and farming may be a secondary occupation and source of income. Regional concentration of livestock herds is shifting.

■ Increased efficiency that causes increased production from fewer herds is especially evident in the dairy cattle industry and increasingly evident in the swine industry. Feedlot production is highly specialized; however, the beef cattle industry has a limited amount of vertical coordination in contrast to the broiler industry, which is less concentrated but has a high degree of vertical coordination.

■ Dairy producers are the largest users of veterinary and animal health products and services. Swine practitioners generate the highest individual revenue. Dairy cattle practitioners generate the highest percentage of revenue from livestock products and services, whereas sheep practitioners depend on pets and horses for more than 50% of their revenue. Beef and dairy practitioners generate about 90% of their revenue from bovine services. Sheep and swine practitioners generate about 25% of their revenue from bovine services.

■ Beef, dairy, and sheep practitioners generate more than 60% of professional service fees from technical services, whereas sheep practitioners generate more than 40% of professional service fees from consultative services.

■ Animal health and veterinary medical expenditures increased at a greater rate than all prices paid by farmers. The ratio of animal health products to services has increased, especially in large herds. Animal health and veterinary medical expenditures per animal decrease significantly as herd size increases. This implies that large herds generate less veterinary revenue for a given number of animals than do small herds (Gehrke, 1995c).

■ Producers perceived local veterinarians to be very knowledgeable concerning diagnostics, treatment, and reproduction, moderately knowledgeable in areas of herd management and nutrition, and the least knowledgeable in agribusiness and economics (Gehrke, 1995a).

■ Producers perceive veterinarians to be highly cost effective concerning reproduction, diagnostics and treatment, but less cost effective than producers themselves concerning herd management, nutrition, and agribusiness and economics (Gehrke, 1995b). The producers surveyed in 1994 perceived local veterinarians as less knowledgeable and less cost effective in reproduction, diagnosis, and treatment than producers surveyed in 1985. These results suggest underlying factors that could have negative impacts on future growth of demand for the services of veterinarians.

■ Veterinarians are considered first, second, or third contacts in all areas except agribusiness and economics. Livestock producers believe local veterinarians are important to their livestock operations. They have a high regard for, and a high level of satisfaction with the abilities of veterinarians.

■ Veterinarians rated themselves or consultative veterinarians as the most knowledgeable individuals in all aspects of livestock production. The ratings of veterinarians and producers were consistent regarding reproduction, diagnostics, and treatment but inconsistent concerning herd management, nutrition, and economics.

■ Veterinarians feel that they are important to most aspects of their clients' operations.

■ Veterinarians do not believe that producers consider them herd management consultants, contrary to the belief of producers. Therefore veterinarians may be missing opportunities to expand their practices.

Other Market Studies

Perceptions that producers and veterinarians have about herd health services are important. A survey of veterinarians' and producers' perceptions of herd health services in an area in Saskatchewan, Canada, with about 255 dairy farms,

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found that veterinarians overestimate their services in nutritional consulting and heifer rearing (Giger et al, 1994). The primary determinant of a producer's perception of being on a herd health program was the occurrence of regularly scheduled reproduction visits. Producers who perceived themselves as being on a herd health program also believed that they received more services in the other four main areas of production medicine (milk quality, nutritional consultation, infectious disease control, and heifer rearing). Producers who perceived themselves as being on a herd health program differed from those who did not. The former thought they received more advice and service in the major areas of production medicine than did producers who thought they were not on a herd health program.

Approximately 60% of producers who believed they were on a herd health program indicated that their veterinarian was rarely or never involved in the analysis of their herd records, an activity considered a prerequisite component of a herd health program. The use of the term "herd health" by veterinarians to describe regularly scheduled reproduction visits may explain the high proportion of herd health producers who indicated that their veterinarian was rarely or never involved in analysis of their herd records. The survey found that producers with a comprehensive herd health program, including analysis of records by veterinarians, were clients of two practices. This suggests that comprehensive herd health services are not readily available from all veterinary clinics in that area.

A survey of dairy farmers in England identified the principal characteristics of the farm and farmer that are likely to adopt a herd health scheme (Wassell and Esslemont, 1992a). Larger farms with better educated, more progressive-thinking farmers are more likely to have a herd health service. Those producers who do not have a herd health program feel they do not have the problems to justify the service and the extra cost and effort required. A survey of 566 veterinary practices with dairy farms among their clients found that the majority of the practices were very positive about the benefits of providing a herd health service. However, only one third was providing such a service, and most had attracted only a small number of clients. The size of the practice, in terms of the number of veterinarians and dairy farming clients, was the most significant factor in determining whether a practice was likely to run a herd health scheme, and the age of the veterinarians did not appear to have any effect (Wassell and Esslemont, 1992b).

Modern Marketing Strategies for the Promotion of Health Management

Persuading livestock producers to use health management services has been a challenge for veterinarians. Veterinarians must consider some basic modern concepts in marketing as an aid in promoting health management services. Modern marketing theory requires that veterinarians view themselves as an applied scientist–business person competing in the marketplace. A successful health management program depends on the development of an integrated marketing strategy. It should emphasize providing producers with benefits they desire from traditional veterinary services combined with the benefits desired from a health management program. This requires detailed planning of the health management program that the producer needs, based on good market research. Finally, a realistic pricing policy should be based on cost and demand. A professional and dignified personal approach to each client's needs is necessary to make producers aware of the existence of such health management programs. The personal selling process allows the veterinarian to determine a particular producer's goals, values, and needs so that the basic herd health program can be customized to that producer.

Veterinarians providing health management services to livestock producers must be "knowledge workers" who can help their clients sift through the steady stream of new information related to their enterprise and assist them in making the best decisions. The AVMA has developed a set of marketing strategy cards. Each card contains a single marketing activity (Clevenger, 1996). For each activity, the marketing objective is listed along with the resources needed to implement the activity, the probable consequences of doing it, and the amount of risk it poses to the practice. Because analysis of data from the 1995 market for food-animal services indicated a need to improve producer perceptions about the value of veterinary services, the strategy cards emphasize improved professional image, public speaking, and client education meetings.

Marketing health management services to food animal enterprises requires the following: (1) defining the veterinarian's mission to ensure that clients are aware of the new direction; (2) developing a structure that integrates the variety of professional veterinary services that are offered, including the development of objective criteria that can measure progress and results in a population; (3) identifying the resources now supplied by the veterinary practice and broadening them into a wider package of services and products, including computer programs for animal health and production; and (4) learning the skills of communication, persuasion, and negotiation.

Animal Health Economics

The traditional veterinarian views disease as evil, and often embarks on a career with a 'Superman' like determination to destroy it, regardless of how important it is. To the classical healer, economic considerations are secondary. The economist on the other hand sees animal disease as just one, and often an insignificant one, of a great spectrum of constraints to human and societal well-being that needs to be put into context, and sometimes seems to take pleasure in spoiling the veterinarian's fun.

(Perry and Randolph, 1999)

Principles

Economics is one of the essential components of animal disease control at all levels in society and in all corners of the world (Morris, 1999). Economics is concerned with the allocation of scarce resources to competing uses, thereby providing the greatest benefit to society. The resource to be allocated is commonly money, but other limiting resources (labor, land) can also be considered. The benefit can be interpreted in a number of ways, depending on the particular circumstances to which economic principles are applied. Both animal and human welfare benefit from the improvement of animal health. The benefits to animal welfare cannot be translated readily into economic terms, but the benefit to human welfare can be expressed to a large degree in economic terms; hence the merits of alternative activities can be compared. Most of the economic benefit can be expressed in monetary terms (e.g., more animal products available for sale, a higher price per unit of product, lower production costs), but some elements cannot be valued so easily in monetary terms (e.g., reduced risk of human infection with zoonoses, increased work capacity of animals in crop production and transport, and increased availability of animals for cultural purposes).

The scientific foundation for the discipline of animal health economics was described in the early 1970s by Morris in Australia and Ellis in England (Dijkhuizen et al, 1995).

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They successfully introduced a simple but essential economic principle in making veterinary decisions: disease control input should be increased to the level at which the cost of an additional input equals the return from the additional output. This so-called *equimarginal principle* can be considered a fundamentally different approach from the earlier and more common opinion of disease control being an all-or-nothing situation.

Animal health economics is a discipline that aims to provide a framework of concepts, procedures, and data to support the decision-making process in optimizing animal health management (Dijkhuizen, 1992). Controlling the costs of production is critically important in modern livestock farming. Improving animal health and fertility is essential in achieving efficient and economically rewarding production. Current veterinary services are evolving to meet the need for service directed to the needs of farmers through planned disease prevention and control programs and management for optimal health. The application of these services is rarely an all-or-nothing situation. Usually several measures or programs are available, each of them offering a different degree of protection and requiring a different level of investment. Determining the optimal input level, therefore, is to a large extent a matter of economic decision making. This is not only the case for the individual livestock owner, but also for a national government that must determine the optimum policy against specific infectious diseases.

In animal health economics, the relative merits of different approaches to improving the health of an animal population are evaluated in order to make the best decisions on the allocation of disease control resources. The focus of the evaluation is on the *marginal* or additional benefit of intensifying disease control by a small degree, until an economically optimum strategy is identified. This point is reached when the increased benefit achieved by a further small increase in disease control effort is exactly balanced by the costs of achieving that improvement. Up to that point, additional investment has produced a positive net economic benefit.

Economic analysis is not a form of financial accounting. The primary strategy is to rank alternative disease control measures in order of the merit of each alternative and to make the best decision, not to calculate the exact monetary value. A fundamental characteristic of economic analyses is that the analysis is never entirely complete. The aim is to make the best decision given the available information.

The initial applications of economics to the field of animal health centered on the assessment of the total productivity losses associated with a given disease in order to provide a monetary figure reflecting how much the disease costs. These efforts reflected a need by veterinarians to demonstrate the importance of the disease in order to justify their research or development activity and give an indication of the potential benefits that might accrue in the absence of the disease. However, with all diseases, it is often unrealistic to present the total cost of a disease as if that figure can be saved. Disease eradication, the means of saving total losses, is only a realistic option under a very limited set of circumstances and for very few diseases. For example, among the parasitic diseases, most of which are endemic and in which the environment plays a key role in supporting development stages, eradication is rarely an option. Thus the determination of total losses has severe limitations as a useful decision support aid.

Economic Losses from Disease

The claim that a particular disease of food producing animals in a herd or region is responsible for large economic losses may indicate that the disease is responsible for impressive losses. However, the results cannot be used for making decisions about research priorities or funding control efforts. It is generally assumed that under the principle of diminishing returns, the marginal cost of control will rise as disease is reduced. The responsible decision maker would need to know how much control can be envisaged for a disease before the threshold is reached at which pursuing control is no longer physically or financially reasonable. That is the essence of impact assessment. Moreover, the decision maker must be convinced that pursuing control of a disease is the best use of scarce resources and must be able to consider the trade-offs made when funding efforts for one disease versus another, requiring yet additional information (Perry and Randolph, 1999).

The effect of animal diseases in a given production system is to reduce the efficiency with which inputs are converted into output-decreased productivity. This effect can result either by decreasing the value of outputs for a given level of inputs or by requiring a higher level of inputs to achieve a given level of output, or both (Rushton et al, 1999). There are various mechanisms by which disease affects animal productivity. Losses may be direct or indirect. The direct reduction in productivity caused by disease can result in losses that are clearly visible to the farmer. These losses may include the following:

- Death of affected animals due to diseases such as anthrax or blackleg
- Lower milk yield caused by subclinical mastitis
- Reduced feed intake because of lameness and inability to graze adequately

Examples of invisible losses include:

- Reduced pregnancy rate and calves not born, which represent unrealized income potential
- Failure to cull unproductive animals when appropriate
- The presence of endemic diseases such as Johne's disease in a dairy herd

Indirect losses include the following examples:

- Additional costs for treatment and control of clinical disease
- Use of outdated production technology
- Reduced or denied access to markets because of the presence of disease or political embargoes

The total cost of disease (C) is the sum of the production losses (both direct and indirect) (L) , and control expenditures (E) (Rushton et al, 1999):

$$C = L + E$$

In addition to the economic impact, diseases and intensive livestock enterprises can affect animal and human welfare. Faced with this complexity, it is not surprising that the economic implications of animal diseases and the control of animal disease are understudied.

The direct costs associated with 30 different endemic diseases of farm animals in Great Britain have been estimated (Bennett et al, 1999). The spreadsheet models and supporting documentation can be accessed at http://www.rdg.ac.uk/AcaDepts/ae/AEM/livestockdisea/ (accessed January 29, 2001).

Economic Modeling Techniques

The four most common economic modeling techniques are *partial budgeting, cost-benefit analysis, decision analysis,* and *systems simulation,* all of which can be applied on three levels of veterinary decision making: the animal, the herd, and the national level (Dijkhuizen et al, 1995). There are considerable differences between published economic

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evaluations and the losses from one and the same disease. These differences may be due to the structure of the farming system, the disease-related loss-making factors that are taken into account, and the way these are calculated (Rougoor et al, 1996).

Decisions can be made at three levels: the animal, herd and the national level (Dijkhuizen et al, 1995). At the individual animal level, decision-tree analysis is most often used to decide whether or not to treat an animal. The analysis has traditionally included probability distributions of possible outcomes. However, the technique itself cannot help the practitioner determine the economic value to include in case of premature disposal of the animal. Many applications include the slaughter value of the animal, whereas others choose to use the cost of purchasing a pregnant replacement, sometimes adjusted by the salvage value. One source has suggested that the following value be included: the value that equals the difference between (a) the income that the animal could earn during her remaining expected life, had the reason for replacement not presented itself (given normal probabilities of disposal because of other reasons) and (b) the expected income over the same period of time of replacement animals with normal productive qualities and normal probabilities of disposal (Dijkhuizen et al, 1995). This value is called the *retention pay-off (RPO)* and enables ranking of individuals within the herd on their expected future probability: the higher the RPO, the more valuable the animal. A value below zero means that replacement is the most profitable choice.

At the herd level, many trials have been done to investigate the economic value and attractiveness of health management programs. These programs are based on regularly scheduled visits to the farm, which this book describes in detail for each species or class of animals. The economic value of such programs is based on changes in disease incidence and improvements in performance using partial budgeting. A detailed economic analysis requires data from both the "with" and "without" health management groups, both by collecting data from "before" (b) and "after" (a) application of the health management program and by collecting data on farms participating in the program (P) and on comparable control farms (C). When available, these data make it possible to estimate the causal effects of the program more precisely. In its simplest form, the analysis is done according to the following formula:

$$(P_a - P_b) - (C_a - C_b)$$

Additional details on the economics of animal health in farmed livestock at the herd level are available (Marsh, 1999).

Economic analysis at the national level is not a simple addition of analyses as done at the farm level. The approach is entirely different and based on principles derived from "macroeconomics" (Dijkhuizen et al, 1995).

Animal health programs can provide a high return on investment because reduction of the impact of disease increases the efficiency of production, often without the need for additional inputs such as feed or labor (Marsh, 1999). Because the economic impact of most diseases that affect farm livestock is typically greater at the subclinical rather than the clinical level, animal health management often involves decisions regarding expenditure on preventive measures as well as the treatment of obviously sick animals. Most decisions in animal health economics at the farm level can be made by using partial budgeting, decision tree analysis, or cost-benefit analysis techniques. The use of economic surplus analysis, with preweaning mortality as an example, demonstrates the importance of improving livestock production efficiency in the face of international competition and how consumers gain from improved animal health (Ott et al, 1995).

The economic benefits of a neonatal calf health program can be evaluated using computer simulation of a multiple-year spreadsheet model, using economic and production variables (Larson et al, 1998). Actual economic performance data from a herd over a period of years can be compared with a projected simulation in which morbidity and mortality are decreased. A sensitivity analysis for the simulation model can also be applied. In a beef herd, for example, the mean per-cow increase in net income for the herd during a 6-year period for morbidity and mortality reductions of 20%, 40%, and 60% was $7.44, $14.93, and $22.42, respectively (Larson et al, 1998). Such a spreadsheet decision tool allows the producers to determine the economic value of a management program designed to increase the percentage of calves that remain healthy during the nursing phase, increase the number of calves weaned, and increase mean weaning weight as a consequence of decreases in illness and death of calves. By identifying primary areas of deficiency on a particular farm, management changes then can be ranked on the basis of economic impact.

Costs of Production in a Herd

For most food-producing livestock enterprises, making a profit is a major objective. This can be achieved by increasing production while maintaining the costs of production, or decreasing the costs of production and maintaining the level of production. Inputs include feed, water, fertilizer, vaccines, drugs, labor, fuel, interest costs on borrowed money, capital (land, animals, machinery), and management. Outputs include end products such as meat, milk, and wool. The costs of production can be reduced by using new and cheaper methods of production, including cheaper feed supplies or by increasing the efficiency of production of livestock products by controlling the effects of disease on animal populations. In most intensified livestock operations, in which profit margins are narrow, how much disease can be tolerated? The productivity of a livestock production system could be defined as follows:

$$\text{Productivity} = \frac{\text{Total value of outputs per unit of time}}{\text{Total value of inputs per unit of time}}$$

Veterinarians are becoming involved in the budgeting of livestock operations. A budget can be used effectively as part of ongoing monitoring to provide information on the profitability of the livestock production system. For example, a simple budget in the form of a projected income statement for a pork production profit center would include the breakdown per head sold, per hundredweight sold, and per breeding female place, which would provide an estimate of the overall profitability of the pork production enterprise. Profit is calculated as revenue minus expenses (Marsh, 1999). The details of budgeting and cost accounting are available in other standard textbooks of agricultural economics and in chapters dealing with each species. In dairy herds the costs of milk production should be determined on a regular basis. In the beef cattle industry the cost of weaning a beef calf is of major importance in determining profit and loss. In the feedlot industry the cost of daily body weight gain on a per pound basis is critical in determining profit and loss. Each individual cost item can be evaluated for its necessity and for whether a more inexpensive substitute is available of equal performance value.

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REQUIREMENTS OF A HEALTH AND PRODUCTION MANAGEMENT PROGRAM

The three requirements for a successful program are a progressive livestock producer, an enthusiastic and competent veterinarian, and an animal health and production data and information system. An even more fundamental prerequisite is the establishment or growth of a satisfactory veterinarian-producer-client relationship. Through experience with the veterinarian, the producer becomes confident that the veterinarian can provide good veterinary service oriented to individual animal care and routine procedures. It is imperative that the veterinarian be knowledgeable and skilled in the diagnosis, treatment, and control of disease in the individual animal and in the herd.

Progressive Livestock Producer

The success of a herd health program depends heavily on the quality of a producer's management skills, including the desire and ability to comply with the recommendations of the veterinarian and other agricultural advisors involved. The identification of key farms who are potential herd health clients in a practice area is crucial to the success of a program (Wassell, 1995). The personal characteristics and attitudes that are desirable for a producer to adopt a successful health management program that can set an example for the rest of the community are as follows:

- *Leaders in the community.* These are the progressive producers whose opinions are valued by other producers. The producer must have a vision for the future and make a long-term commitment to effective and profitable livestock production. Continuous improvement to reduce variation and systems thinking and innovation are vital activities for success. Effective producers who are leaders do not allow entropy or the dissipation of energy to occur (Humble, 1995a).
- *Successful business people.* Business acumen is a highly desirable characteristic, especially if the producer has a good farm that is the primary source of income. The farm must be large enough to support a cost-effective health management program. These producers are aware of the principle of cost effectiveness and opportunity cost, and net profit from the farm is a primary objective.
- *Information-oriented people.* They recognize the need to keep and use animal health and production records. This is easily assessed by an examination of their records and how they use them to make decisions.
- *Stable, efficient producers.* They have good judgment and are recognized as "innovators" in the community (Fig. 1-2).
- *Knowledgeable producers.* These are producers who keep up to date with the farm literature and are interested in learning more about the modern aspects of animal health and production. They recognize the interactions among reproduction, nutrition, mastitis, milk production, and calf health management. They express interest in health and production management and appreciate the contributions that veterinarians can make, in addition to their traditional role in emergency veterinary medicine.
- *Producers who have not overextended their limit of resources in terms of finance and of labor or land area.* They are most likely to be able to make changes in management and scale of operations.
- *Producers whose inclination is to avoid taking risks.* They are natural enlisters in herd health programs. There are significant differences between them and high-risk takers in farming performance. Highly risk-averse producers may request veterinary services that can complement and improve management (Antle and Goodger, 1988).

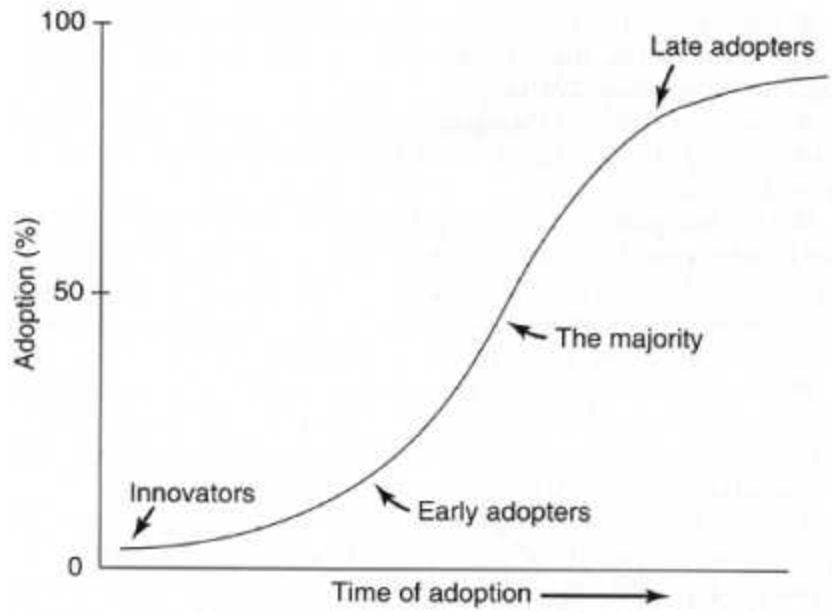

FIG. 1-2 Community adoption curve.

The development of a situation in which producers are committed to a herd health program requires two stages. The first is to convince them to begin by establishing a bond of confidence between the producer and the veterinarian, by determining that there is a problem in the herd that is likely to be responsive to a cost-effective control program, and, if necessary, by beginning the program on a partial basis (Wassell, 1995). For example, starting a program to improve reproductive performance or udder health and milk quality, and delaying action on other problems until obvious results are obtained, constitutes a partial program.

Herd health management programs need to be viewed from the perspective of the livestock producer's decision-making framework. The producer's goals and objectives must be considered first. The producer's resource situation may be a primary determinant of feasible herd health alternatives. The role, nature, and size of livestock enterprises impose varying degrees of limitation on the type and scope of a herd health management program that is economically feasible, workable in practice, and acceptable to the livestock producer.

Having established a program in a herd, the challenge for the veterinarian is to maintain it. A successful program has the following characteristics, which are attractive to progressive producers:

- The simplest data recording system possible. A producer's natural inclination is to avoid paperwork, especially large sheets of it showing many columns and figures. Data such as milk test results may already be provided on a regular basis but are not being used. The producer's observations should be restricted in scope, if possible, to the most important data. Also, these should be transcribed, collected, and entered into the database by proficient data handlers.
- The quickest possible turnaround time for analysis of data and reporting back to the producer. Instant turnaround by computer printout or visual display is most satisfying. Reporting back in numerical terms is usual, but, if the results can be expressed in financial terms, they have more meaning to the producer. The veterinarian's use of portable laptop computers and spreadsheet programs during farm visits provides the opportunity for rapid data analysis and the generation of useful information.
- A data analysis system that gives early warnings of impending deviations of production performance or disease prevalence from set targets and goals.

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- The introduction into the production and disease control systems of the most up-to-date technical information as soon as it becomes available.
- The creation of a database of information accumulated from many other farms to serve as a realistic guide to targets of performance.
- The calculation and preparation of anonymous inter-herd comparisons to indicate to producers where they stand with respect to performance in a variety of parameters and in contrast with peers. The intention is to motivate producers to consider how production can be improved.
- The promotion of exchange of information among producers about modifications of techniques, problems with existing techniques, and developing needs by conducting group meetings at intervals of 6 months to 1 year.
- Visiting the herd regularly, punctually, and for a sufficient time period to allow discussion of all management areas and problems. In beef cattle or sheep operations, where farm visits are less frequent, the maintenance of surveillance must be less personal but can be complemented by written reports at intervals between physical visits.
- Ensuring that farm staff, especially managers and partners, are included in the progressive atmosphere of the program. Inclusion of these people is critical because they are responsible for putting the recommended procedures into practice.

These parts of a total program are displayed in Fig. 1-3. They all encourage motivation of the producer to continue with a health management program. They also impose an acceptance of responsibility by the veterinarian to provide the necessary input, to keep on providing this input, and to be financially responsible if the wrong advice is provided.

Enthusiastic and Competent Veterinarian

A successful health and production management program depends heavily on the enthusiasm and competence of the veterinarian providing the service. Most veterinarians who are active in herd health began their careers in large animal practices, which provided primarily emergency veterinary service on an individual animal basis. As they developed sufficient experience and confidence with their clinical skills, they directed their interest toward health management of the herd or flock. By providing herd health services to a few producers initially, they learned about the importance of integrating health and production management. Veterinary associations and colleges responded to the continuing educational needs of these veterinarians by providing conferences and workshops that dealt with various aspects of herd health in each of the food-producing animal species. Gradually, these veterinarians expanded their services to the point where many now spend most of their time providing herd health services. They were self-taught and sought out as much information as they could find to assist them in developing herd health programs for their clients. Much was learned by careful observations of animal health and production techniques on some farms, which could be transferred to other farms. These experiences indicated targets of performance that could be applied to farms beginning a herd health program. These veterinarians were convinced that they had a vital role to play in cost-effective health management and production. They were production-oriented clinicians who placed more emphasis on the management factors that promoted optimum health and production than on the treatment of disease.

Veterinarians who serve the food animal industries have a general background in veterinary medicine combined with knowledge and skills in animal production, animal disease, production economics, systems analysis, and information management. They are specialists in the sense that they have a thorough understanding of a particular livestock species or class of livestock, and of the industry with which they work. The efforts of these specialists in production-oriented health management are directed toward the livestock enterprise and not merely the individual animals. They can provide producers and managers with information and advice on all aspects of the livestock components that influence health, productivity, and profitability. A farm information database that contains relevant data on health, production, and environmental factors is a necessity in order to make data-based decisions. The veterinarian must be able to analyze production records and identify the areas of the production cycle that need further investigation.

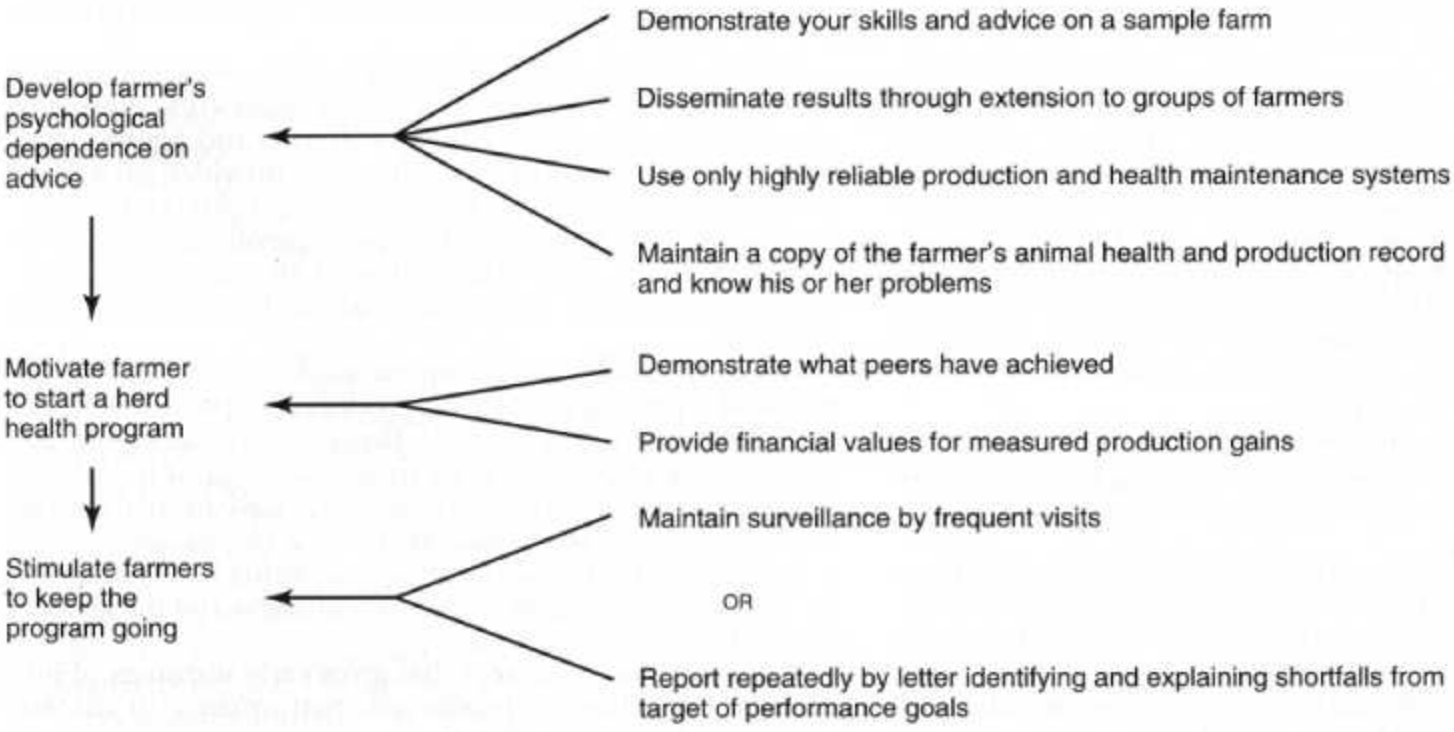

FIG. 1-3 Converting farmers to a herd health service.

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Those working with a number of similar farms can draw inferences from one set of production and management circumstances and use them to help explain or predict circumstances on another farm.

Livestock producers are seeking information from veterinarians on how to manage their individual enterprises and maximize profitability. They are interested in specific information on nutrition, housing, genetics, drug therapy, vaccinations, use of estrous synchronization techniques, and sanitation procedures, to mention some examples. Producers need the assistance of unbiased experts, like veterinary species specialists, to use the highly technical information that is available in order to make traditional management decisions. Producers turn to veterinarians to relate the vast amount of information to their particular enterprise. This means that these veterinarians need good verbal and written communication skills, which can be acquired with practice. It means spending large amounts of time analyzing records and writing concise reports, which are sent to the producer. A broad liberal education is an asset.

Species and Industry Specialists

Veterinarians who provide the services just mentioned have to become knowledgeable about a species or class of livestock and about the economics of production, clinical epidemiology, nutrition, housing and environmental management, reproductive performance, control of infectious diseases, and marketing aspects of the industry with which they work (Pritchard, 1989b). They should be committed to the role of the veterinarian in production-oriented veterinary medicine as species specialists (Blood, 1979; Radostits, 1989). The need to provide a broadly based, totally integrated, planned animal health and production management veterinary service should be a high priority for them and their practice. As multiple-person practices become more common; they allow individual veterinarians to specialize in a species or class of animal and to spend the time necessary to provide a competent service that is based on reliable health and production information. *The veterinary practice must be able to make a long-term commitment to providing a health management service.*

Problem-Solving Skills

Problem-solving skills are a major asset in learning and practicing health management. Veterinarians must be able to identify the problem; access a body of relevant knowledge from personal memory and experience, from a consultant, or from textbooks, journals, or computerized databases; apply the information to the solution of the problem; and evaluate the response. Keeping up to date with the veterinary and agricultural literature related to a species or class of livestock is a necessity and a challenge. Veterinarians generally find it difficult to be informed about new and useful information in the published literature because clinical practice usually takes priority over reading journals and filing articles for future reference. A personal library in which articles can be stored and retrieved quickly is a necessity. On-line computer searching of the literature to obtain the latest published information needed to solve a problem is now a reality. Veterinary colleges and practitioners will need to develop a variety of important competencies for lifelong learning (Stone et al, 1992).

Clinical Epidemiology

Clinical epidemiology is an integral part of health and production management and is an important part of the education and skill of veterinarians in food animal practice. New approaches to animal health problems include more observational studies, which interact with the disciplines of sociology, economics, and mathematical analysis (Davies, 1985). In the past, the lack of herd level expertise contributed in part to the lack of demand for veterinary services by livestock producers. Veterinary graduates were educated to deal with the individual animal but were not prepared to solve herd-level problems. As a result, many herd health recommendations were based on extrapolations from traditional individual-animal medicine. A major challenge for the veterinary profession is establishing expertise in herd-level decision making based on appropriate comparisons of herd-level treatments among sufficient numbers of farms. Clinical epidemiology can be used to conduct clinical and field trials, to test the efficacy of vaccines or a new drug, and to determine whether a particular herd needs a dietary supplement because of a suspected nutrient deficiency in the area. For example, the components of swine production—genetics, feeds and feeding systems, housing, record keeping and analysis, disease prevalence, and production scheduling—are constantly changing. Ideally, to remain current with these changes, a swine practitioner needs rapid access to the latest, well-reasoned, and scientifically supportable facts. However, commonly they are faced with the difficult task of differentiating scientific fact from huge volumes of testimonials and anecdotal accounts (Straw, 1997).

Computer Literacy

Computer literacy is a necessity for any veterinarian providing health management services to the food animal industries. Computers can be used to analyze health and production data, determine the response to treatment in feedlot cattle, transfer data from central data banks (such as the Dairy Herd Improvement Association) to the veterinarian's office, help formulate rations, access literature from computerized library databases, and prepare regular client newsletters and herd health reports. The use of portable laptop computers allows for the collection and analysis of data by the veterinarian during the farm visit so that the producer can have a quick summary of performance, ration formulation, and other computer outputs on the same day as the farm visit. This also allows the veterinarian to demonstrate to the producer the time it takes for the collection and analysis of data and to determine appropriate charges for the service. This is in contrast to the practice of the veterinarian analyzing the data back in the office, with the producer not fully appreciating the effort involved and thereby being reluctant to pay for the service.

Postgraduate Certificate Programs in Food Animal Health Management

Veterinarians interested in herd health have traditionally done emergency veterinary work for a few years and gradually increased their expertise in herd work by self-directed learning and by working intensively in several herds over a period of years, learning by experience. Practical experience has been combined with attendance at continuing veterinary education short courses, which concentrate on the health and production aspects of a species or class of livestock, such as dairy health management. The veterinary profession and veterinary colleges have traditionally accepted that specialization occurs following graduation and entry into private practice. However, the growth of well-qualified, specialized veterinarians has been slow, partly because of an insufficient number of quality formal postgraduate training programs suited for the veterinary practitioner who cannot

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afford the time or the financial resources to enroll in a conventional postgraduate program of 2 or 3 years' duration.

Some formal postgraduate courses in production-oriented health management in each of the species are now being offered by veterinary colleges and veterinary associations. The Post-Graduate Committee in Veterinary Science of the University of Sydney in Australia has offered highly successful refresher courses in health and production management for each of the food-producing animal species. The courses are several days in length, and lecture notes are made available at the course. The Australian Veterinary College of Veterinary Scientists offers memberships and fellowships by examination in almost any species selected by a candidate. Studying for the examination and becoming a member or fellow of the college provides a camaraderie that serves to promote and encourage communications and improved practice standards.

At its annual conference, the American Association of Bovine Practitioners now offers about 20 preconvention seminars on all aspects of health and production management of dairy cattle, beef cattle herds, and beef feedlots, including clinical epidemiology and quantitative methods for veterinary practitioners. Because the emphasis in these seminars is on small group teaching, enrollment is limited and they are usually oversubscribed, which indicates that practitioners recognize the need for specialized knowledge and skills. The American Association of Swine Practitioners also has an annual continuing education program for swine practitioners. The Royal Veterinary College of Veterinary Surgeons in the United Kingdom certifies practitioners by examination in swine medicine and production. The American Board of Veterinary Practitioners offers certification by examination within a food-producing animal species. The objective of the board is to promote species-oriented clinical practice as a specialty in the veterinary profession. It encourages excellence and advanced certification among practitioners, which should raise the standards of practice. The examination requires that the candidate have a multidisciplinary understanding of the health and production of a particular species, which fits well with the knowledge and skills required for a food animal veterinary specialist.

Certificate programs are a developing area of continuing education that will become much more important in the future as a means of ensuring continued or improved competency for practitioners. In general, certificate programs are structured, intensive continuing education programs designed to meet specific needs for a particular audience (Chenoweth, 1996). These programs attract individuals who are not necessarily interested in graduate degree programs, yet desire more intense training than that usually provided through conventional continuing education programs. Certificate programs focus on a specific area or need and are designed for individuals with at least 2 years of experience in clinical practice.

In 1990, at the Ontario Veterinary College in Guelph, Ontario, the Dairy Health Management Certificate Program was begun for dairy practitioners. It is a postgraduate program for dairy practitioners who desire to increase their expertise in dairy health management. The program extended over a period of 2 years and consisted of 13 modules, each 3 days in length, during which lectures and seminars were presented. Small-group problem-solving exercises based on actual dairy farm health and production problems were emphasized. Topics included monitoring of animal health and production, clinical epidemiology, nutrition, mastitis control, reproductive performance, control of infectious diseases, environmental management, rearing calves and herd replacements, genetics improvement programs, milk quality control and residue avoidance, economics of milk production, and implementation of health and management services. The participating veterinarians concluded that the program was successful and recommended it as a model for postgraduate education programs for veterinary practitioners wishing to specialize in a species or class of livestock.

The Pennsylvania Dairy Production Medicine Certificate Program began in 1991 and graduated its first class of dairy cattle practitioners in 1993 (Moore et al, 1996). The curriculum consisted of 10 modules, each 2 to 3 days long, devoted to topics of dairy production medicine. The effect of participation by veterinarians on herd performance and management practice of the herds serviced by veterinarians indicated a positive effect of the program. At the end of the study, treatment herds were three times more likely to review herd performance with their veterinarian and monitor heifer growth, and two times more likely to set goals and conduct adequate estrus detection than were control herds. In dairy herds serviced by participating veterinarians, the mean age at first calving decreased and the prevalence of many good management practices increased compared with herds served by veterinarians who did not participate in the program. Management practices that require inputs of time or money, such as estrus detection, culturing for mastitis, tape-weighing heifers, and body condition scoring are less amenable to change, and prevalence of these practices in control herds did not change over the course of the study.

Food-producing animal practitioners are now more business-oriented than veterinarians have been in the past even though most veterinary graduates do not have any formal education or experience in the business management of a veterinary practice or a livestock farm. Veterinarians tend to look on themselves as professionals first and as business people second, or not at all. As the emphasis on livestock farms shifts from increasing food production to business management, it is necessary for veterinarians to have some business management skills if they are to be accepted as advisors.

Undergraduate Veterinary Curriculum

There is now much interest in the content of the undergraduate veterinary student curriculum and in the postgraduate continuing education programs, which are necessary for preparing veterinarians to provide herd health services to the food animal industries. The undergraduate curriculum of most veterinary colleges has provided a broad-based veterinary education in the preclinical and clinical sciences. At least one veterinary college (North Carolina State University, College of Veterinary Medicine) has provided an active learning program for undergraduate students to integrate production medicine with the veterinary curriculum by providing an animal teaching unit for students to gain hands-on experience with commercial herds of animals in a farm setting (Oxender and Harrington, 1992). The students work in the herds on a regular basis and gain experience in population medicine and animal production. The student learning objectives include the ability to perform many clinical skills and to understand some elements of health maintenance and animal production.

Historically, veterinary graduates have practice-entry knowledge and skills for general, small, and large animal veterinary practice. With some exceptions, there has been limited opportunity in the undergraduate curriculum for students to concentrate their studies and clinical experiences in one or a few of the preferred domestic animal species. In addition, most veterinary colleges do not have a large enough clinical caseload to provide sufficient on-farm experience for students who might choose to focus their efforts on a single species or industry. Also, the traditional residency–board specialty program, at least in the United States, has been

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very much discipline oriented, not species-industry oriented. There is a need for formal postgraduate residency and degree-granting programs in a species specialty such as swine practice, beef cow-calf practice, and dairy cattle practice.

Veterinary education programs to meet societal needs of the 21st century have been well described (Pritchard, 1989b). In essence, veterinarians should have a broad-based liberal general college education in subjects such as languages and communication skills, art or esthetics, history, human institutions, nature, science, mathematics and quantitative problem solving, psychology, and social studies. Individuals with such broadly diverse backgrounds and interests are more flexible, creative, adaptable, and active in community affairs and better able to overcome personal crises. The professional veterinary curriculum should provide students with the essential information, skills, behaviors, and attitudes that should be possessed by a veterinarian. The goal of the professional curriculum should be to develop an understanding of the principles of biology as they apply to animal health and diseases (and their prevention and control in animal species of importance), and to develop clinical skills in the application of this information to the solution of animal health and production problems. It suggested that the principles of health management courses in veterinary curricula could be taught using the problem-solving approach (Goodger et al, 1994). Students are given examples of real life clinical problems that must be defined and explored, and action plans that must be described, for solving the problem, including implementation and evaluation. The focus of the educational process should be on the acquisition of skills for finding and using information to solve problems. In addition, the necessary behaviors and attitudes of the veterinarian should be emphasized.

It has been suggested that the four essential components of a veterinary education for the 21st century are as follows (Thornburg, 1992):

- Broad-based education
- Critical thinking skills
- Diagnostic competency
- Desire for lifelong learning

Among the recommendations of the PEW National Veterinary Education Program's Future Direction in Veterinary Medicine was that, in their education, veterinarians develop "skills in oral and written communication" in the management of information and in business and management. Communication is more than just the ability to write or speak well. Communication is about the process of respectfully interacting with oneself and others and is an exchange of information, feelings, and values. It includes intrapersonal communication (self-understanding, self-evaluation, and reasoning) and interpersonal communication (interaction with others, relationships, and self-disclosure). Through interpersonal communication, relationships are started, maintained, or destroyed. Good communication thus involves an understanding of self-awareness, self-esteem, feelings, and emotions, and the development of listening skills and the willingness to disclose oneself truthfully and freely. Good communication also requires an understanding of the principles of language and verbal interaction, including barriers to this interaction, principles of language of nonverbal communication (body language), and interpersonal communication and relationships (relationship development and deterioration, improvement of interpersonal communication, conflict management, interviewing skills). Veterinarians must learn about group and organizational communication dynamics and how to enhance effective communication in these contexts. Development of these additional skills need not be left to chance. They can be taught by people trained in the area and could be part of a management and interpersonal skills course for veterinary students. The time has come when veterinarians should be expected to graduate from all veterinary colleges with a reasonable understanding of the basis of communications (Prescott et al, 1994).

In the traditional clinical instructional program of most veterinary colleges, the student was required to spend some time in each of several different clinical rotations, which included both small and large animal species. There was insufficient opportunity to obtain in-depth knowledge in any particular practice subject. By trying to get some clinical experience with each of the domestic animal species, veterinary students did not get enough clinical experience with any one class or species of animal, which would have given them the confidence needed to provide quality veterinary service for a particular species in a clinical practice situation. On the day of graduation, each graduate was essentially a generalist. Only after graduation, and by entering a practice in which it was possible, could the veterinarian pursue a personal interest in the clinical veterinary medicine of a species or class of animal. There was no flexibility in the curriculum that allowed students to explore an area of interest.

Core-Elective Veterinary Curriculum

The core-elective programs, now being considered and instituted by many colleges, permit students to focus interest and expand their knowledge of certain branches of veterinary medicine. It is now proposed that the clinical instruction program permit the student to acquire an advanced level of clinical understanding and skills with a single species or class of animals by selecting such a clinical track at some time during the last 2 years of study. This would allow the student to achieve a higher level of clinical competency within the 4-year professional curriculum. The electives would have to be as rigorous as the rest of the curriculum, and the development of scholarly electives should be a challenge for the veterinary faculty. Species selection could come early in the curriculum to allow a maximum concentration during the 4-year period. Not every veterinary college would be able to provide clinical instruction in every species because they would have neither sufficient clinical practice nor the faculty to support the undergraduate and graduate teaching programs. However, if each veterinary college in the United States and Canada were to develop one or two centers of clinical excellence based on the opportunities currently available in their area, such centers would attract undergraduate students worldwide who desire in-depth clinical instruction in a food-producing animal species (Pritchard, 1989a). For example, if the colleges in the major swine-producing states were to develop such a teaching center with clinical swine specialists, the students interested in swine production would receive the education and experience required to become a swine specialist much earlier, before graduation, which would be a comparative advantage when entering practice. These are exciting prospects. The educational process will have to become more flexible to allow students greater choice with current DVM programs and from production animal expertise in other programs and institutions (Chenoweth, 1996; Hubbell and Shaffer, 1998).

To provide quality undergraduate and graduate education in food-animal health management, the veterinary profession and veterinary educators must also give research and education a higher priority than currently is the case (Cornelius et al, 1993). This will require a change in the culture of the profession and in the attitudes and practices of veterinary medical educators. Veterinary medical colleges must increase their research effort, and veterinary investigators must participate more fully in the nation's competitive, grant-supported, high-priority biomedical,

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environmental, and agricultural research agenda. Strategies must be developed to enable clinicians aspiring to academic careers to obtain solid research training in addition to clinical skill training obtained in residencies. Veterinary college clinical faculty must be species specialists who work in a real-life teaching clinic with an adequate clinical caseload or an adequate number of farms being serviced by the veterinary teaching hospital.

With the decline in clinical caseloads in the food-animal sections of veterinary teaching hospitals of veterinary colleges, the alternative of providing clinical experience to students by sending them into private veterinary practices as externships has been instituted in some situations (Dartt et al, 1997). Practice-based ambulatory rotations can be a good alternative to existing university-based ambulatory rotations for undergraduate students (Dartt et al, 1997). However, most of the emphasis was on clinical procedures (physical examination, surgery, general medicine), with limited emphasis on herd health management. Providing a comprehensive clinical education and experience in health management of any of the food animal species will require herds to be visited on a regular basis, data to be collected and analyzed on a regular basis, and recommendations to be made and results monitored on a regular basis. Such an experience requires sufficient time, mentoring by experienced clinicians, time and resources for library searching, and effective feedback. It is doubtful such a teaching and learning experience can be provided in private practice.

Animal Health and Production Data and Information Systems

Principles

One of the most important components of any successful herd health program is keeping good records that can be used to monitor animal health events, levels of production, and the incidence of disease. A simple, reliable system of recording animal health events and production performance is a fundamental requirement for a successful herd health program. Without recording, the analysis of productivity involves guesswork, and the recommendations for improvement cannot be made with confidence. Crandall (1980) said, "When performance is recorded, performance increases; when performance is reported, performance is accelerated." The records system involves all components, from the records containing raw data to the summaries of animal health and performance. Many different systems are available, but the fundamental requirements include the following:

- Positive identification of the individual animal or groups of animals is a necessity. For example, the Canadian Cattle Identification Program began January 1, 2001. The program involves the individual identification of all cattle that move beyond their herds of origin with approved ear tags bearing numbers that are unique to each animal. More information is available at www.cattle.ca/ccia.
- The system must be simple to use and understand.
- Only animal health and production data considered necessary to assess herd performance are monitored and analyzed. The types of data collected vary among species and classes of livestock, but clearly established standard terminology should be used to avoid confusion and to allow comparisons to be made among cooperating farms.
- The system must be structured so that the data are easily collected, gathered, analyzed, summarized, and available to the producer as soon as possible after the herd visit of the veterinarian.
- The veterinarian should maintain a file of each summary report available to the producer.
- In the simplest form of record keeping, the data from individual animal cards or from groups of animals are collected and analyzed regularly, and summaries of herd performance are reported. In small cattle and swine herds, the manual handling of records is satisfactory but can be time consuming. The types of records used vary considerably, depending on the class of livestock and the status of the herd health program. For example, in the simplest and most common form used in dairy herds, there is an individual lifetime card for each cow. All events of the reproductive cycle and incidents of clinical disease are recorded on the card when they occur. At regular intervals, monthly or less frequently, the veterinarian analyzes the data and prepares a summary of the reproductive performance and disease incidence. This type of individual-card manual analysis system can be successful for small, 50- to 80-cow dairy herds. Manual systems have been satisfactory, particularly with the development of new work sheets and calculation aids for the calculation of herd indices. Similar manual systems have been used successfully in beef breeding herds, swine herds, and beef feedlots.

As livestock herds become larger and production methods more intensive, producers become more cost conscious and require the rapid analysis of a wide spectrum of production data, which cannot be performed easily using manual methods. This has led to the use of the computer, which can provide useful performance statistics for decision making on a daily basis. The computer is "automating" the eyes of the producer. The computer is able to store a large amount of data about a large number of individuals. It has the capacity to analyze and integrate current data with historical data and provide a summary of up-to-date performance. It can be programmed to compare actual performance with preset targets of performance and farm goals. The computer can prepare action lists, which advise when certain events will occur or when certain procedures should be performed. It is now possible for the computer to take over the entire chore of record keeping and to provide summaries of performance as frequently as necessary. The farmer needs to make only the most elementary records of observations.

The computer has had a major impact on the development of efficient, modern livestock production. Much of the progress in animal breeding programs in cattle and swine has been made using the computer to analyze genetic merit. Initially, the information from the farm was mailed to the computer center and processed by a mainframe computer, with the report mailed out to the farm. A major problem with this bureau system was the long turnaround time—as long as 2 weeks or more—which often rendered the information obsolete. The introduction of farm-located terminals linked to the central computer by telephone has eliminated this problem. The development of microcomputers now makes it possible for farmers to own and operate a computer completely independent of any outside agency. It is obvious that on-farm computers can be used extensively for analyses of farm accounting, crop production, and livestock performance on individual farms. Veterinarians providing a herd health service must use all the production information that is available from the farm programs. If this is unavailable, computer programs should be developed that are located and operated in the veterinarian's office. The data are sent to the office on a regular basis and processed, and the results are returned to the farm. In this way, both the producer and the veterinarian maintain a record of the health and production of the herd.

In general terms, the flow of data and information in a herd health program participating in a bureau system of data and information management can be represented diagrammatically (Fig. 1-4). The data are collected from

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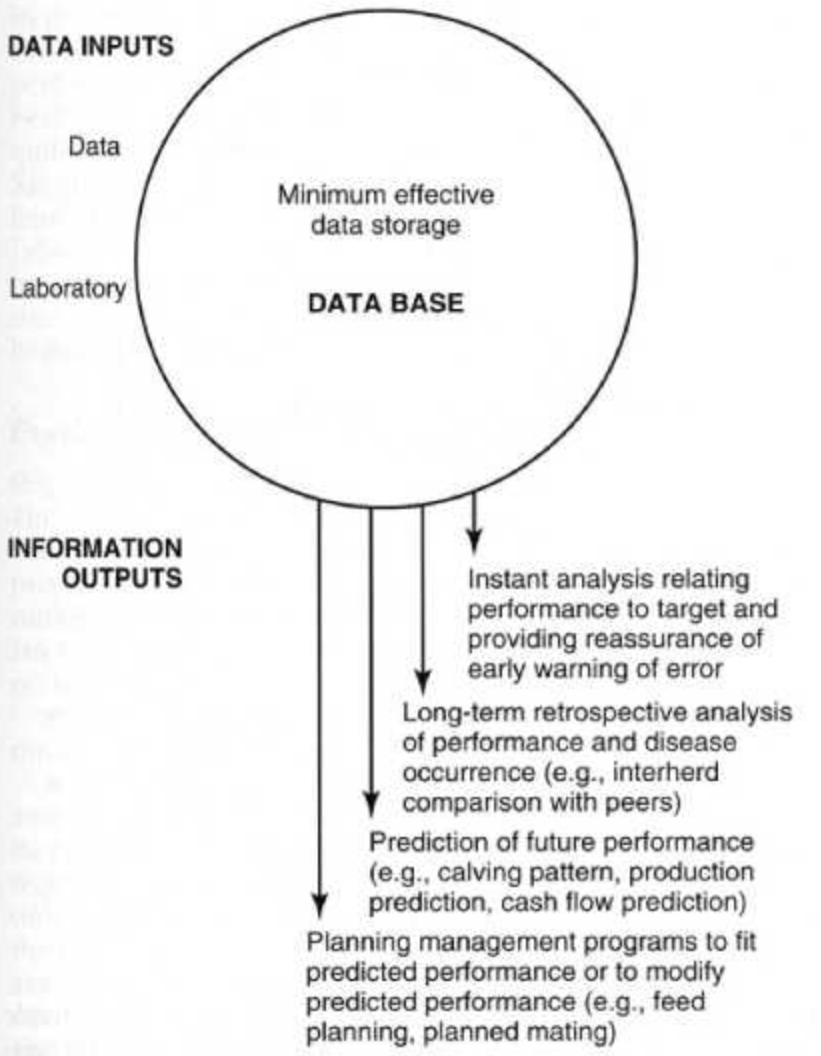

FIG. 1-4 Flow of data and information in a health management program using a bureau system of data collection and analysis.

available sources on a regular basis and entered by codes into the computer, which analyzes the data and produces useful information. The veterinarian must then interpret the information and make recommendations for action to improve performance. The results of the action to improve performance are monitored over the next few farm visits and the cycle is repeated. It is a constant, self-analyzing surveillance system. For each action there is a measurement, and for each period of monitoring there is either more action or a decision that no action is necessary. The targets of performance can be incorporated into the computer program and compared with actual performance. An examination of the computer printout for the period indicates the areas in which shortfalls have occurred.

As shown in Fig. 1-4, data can come from several sources. To maintain the program's profile of economy, and to use information as efficiently and inexpensively as possible, it is necessary to use data already accumulated for other purposes. For example, data from the Dairy Herd Improvement Association (DHIA) services should be directly available. Use of this material can be of considerable economic benefit, especially if it is already computerized and in a compatible language. Only data that are critical to the assessment being undertaken should be collected. It is easy to collect enormous amounts of data that are irrelevant or redundant. The sole purpose of the program is to perform every part of it with the greatest economic efficiency. This applies to data collection and analysis as much as it does to the veterinary part of the program.

The data obtained from participating herds and flocks can be accumulated into a data bank. From this bank, performance levels can be estimated and targets set. This information usually comes to the data bank as a monthly return on a structured report form. It is desirable to accumulate as much basic and detailed information about the relevant animal species and industry as possible. For a practicing veterinarian this may be, although not necessarily, limited to disease incidence and reproductive performance. For a species specialist, the expertise extends into the fields of nutrition, breeding programs, and housing. A collaborative effort with an animal husbandry adviser can complement the service.

Centrally Located Animal Health Data Systems

An example of a central animal health and production database is the Animal Productivity and Health Information Network (APHIN), which has been established at the Atlantic Veterinary College, University of Prince Edward Island, Charlottetown, Prince Edward Island, Canada (Dohoo, 1992). More information is available at www.aphin.upei.ca/index.htm. The network consists of a number of microcomputers linked to a central database. The microcomputers are on farms, in veterinary practices, in the processing industries, in the veterinary diagnostic laboratories, and within the veterinary college. Health and production data from these various sources are entered into the system using the microcomputers, which are linked to the central database by long-distance telephone lines. The function of the central database is to collate, analyze, and summarize the data it receives. Dairy, swine, and beef herds are participating in the program. The central database prepares summary reports of animal health and productivity of all participating herds, which remain anonymous. In addition, reports are generated for individual farms. Only individual producers are able to grant written permission for access to the identification data associated with their farm. The major advantage of this system is that it allows producers and veterinarians to see what health and production performance values are being achieved in the population of animals at large and to compare them with those of individual producers. Such comparisons can serve as a powerful motivating force for producers to improve the efficiency of livestock production. The pattern of flow of information is illustrated in Fig. 1-5.

A computer system for collection of animal disease and related data was begun in 1985 by the Directorate of Veterinary Services in Namibia. The nationwide system consists of detailed disease and herd health data from field veterinarians, disease and related data (such as grazing and animal condition, vaccinations, and farmer treatments) from animal health inspectors, laboratory results and investigations, and abattoir data (Hare and Biggs, 1996). In addition, a socioeconomic component has also been added. It is anticipated that epidemiological studies will be performed using the data.

National Animal Health Databases

Another network is the National Animal Health Monitoring System (NAHMS), which began in 1983 in the United States. Its purpose is to collect, analyze, and disseminate data on animal health, management, and productivity across the United States (King, 1985). NAHMS conducts national studies to gather data and generate descriptive statistics and compiles statistics and information from data collected by other industry sources.

The data for all the food producing animal species is available from the Center of Animal Health Monitoring (CAHM) at www.aphis.usda.gov/vs/ceah/cahm.htm.

The details of the information collected from representative farms are presented elsewhere in this book. The design and implementation of the United States NAHMS 1995 National Swine Study is available (Losinger et al, 1998).

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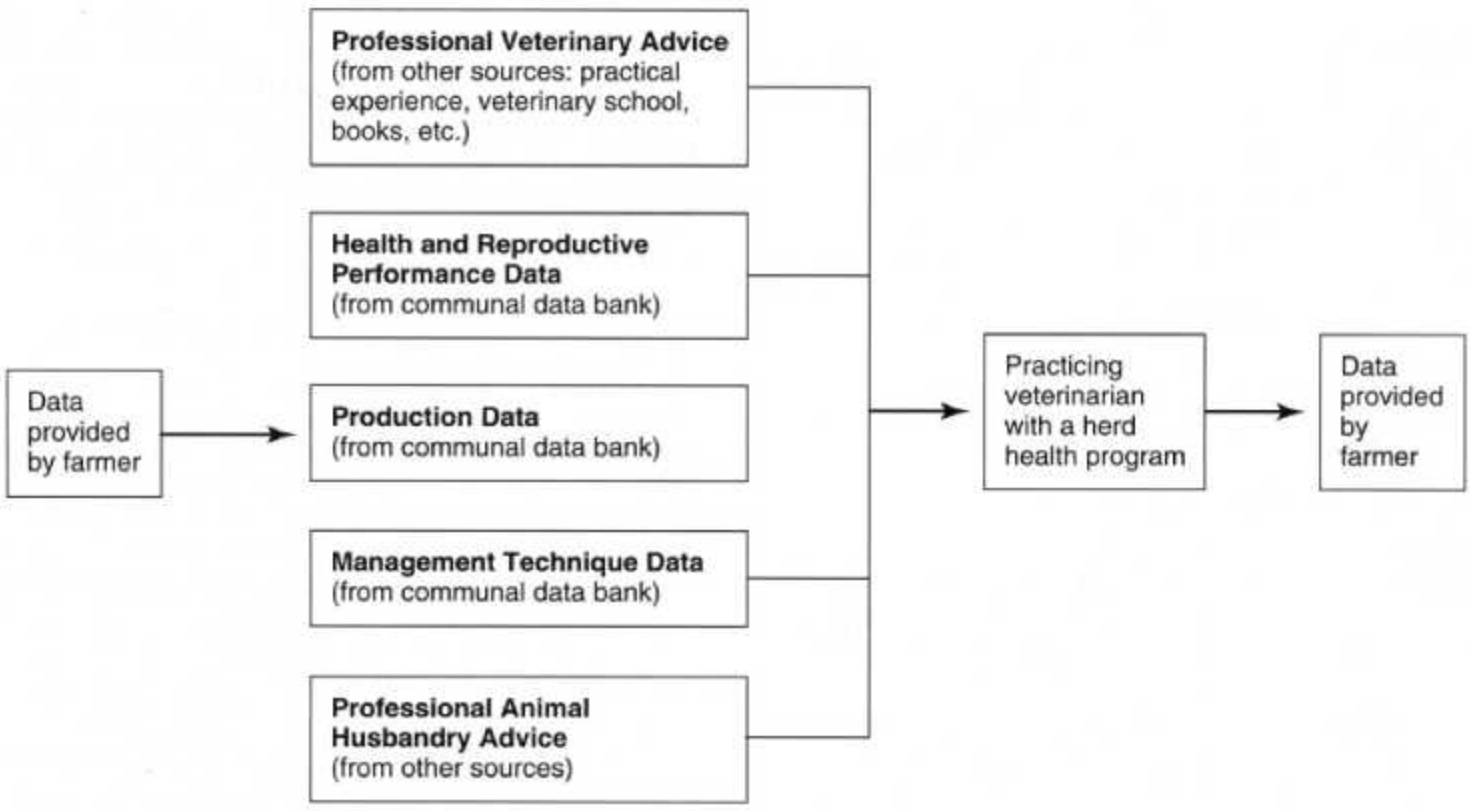

FIG. 1-5 Various sources of data in a health management program using a bureau system of data and information management.

Animal health and disease information systems are important nationally and internationally. The ability of animal agriculture to use information for strategic market advantage is at the center of domestic and international trade competitiveness. As increased demands are placed on animal producers to provide safe, wholesome products for domestic and international markets, real-time knowledge of the national herd is becoming essential (Miller et al, 1994). Countries that develop national-herd information management strategies, and especially those that do so first, will have a decided advantage in the international trading area. At a national level disease control can be viewed as the function of a large regulatory system comprising subsystems represented by states or provinces. Data collection begins at the individual herd level. A national regulatory system also can be viewed as a hierarchic arrangement of state and federal regulatory subsystems and sub-subsystems. At the top of the hierarchy is the strategic planning level, where decisions are made that establish the direction for a national disease-control program. An example of a national information management strategy is the control of pseudorabies in swine in the United States. In 1989 a 10-year effort to eradicate the disease from the swine population in the United States was initiated. It is nearing completion in 2001. To assist states in tracking pseudorabies and program-specific information and compiling quarterly and annual pseudorabies progress reports, the USDA, Animal and Plant Health Inspection Service, and the National Center for Animal Health Information Systems developed the Pseudorabies Monitoring System. This system, which is being used in 21 states, is the only regulatory disease-management software currently in use that allows data sharing among multiple states and the federal government.

International Animal Disease Data Systems

The Office International des Epizooties (OIE) has been developing a world animal health information system to collect and disseminate animal disease information to OIE member countries, to alert countries threatened by epidemic outbreaks, to strengthen international cooperation on animal disease control, and to reduce barriers to the international trade of animals and animal products (Miller et al, 1994). The lack of a standardized information technology management strategy has resulted in state and federal information systems evolving separately, rather than in parallel. The absence of an information management strategy may eventually affect regulatory program management, epidemiologic research, and domestic and international trade.

In Europe, with the introduction of the single market in 1993, all veterinary border checks were abolished and free movement of animals became possible throughout the European Union. A conceptual framework has been described for national identification and recording systems, especially for the control of highly contagious disease in pigs (Saatkamp et al, 1995). Electronic identification and monitoring systems could be an especially important tool in improving collection and subsequent use of information in future animal production.

Analysis of Data

After the animal health and production data are collected from the farm, they must be transferred to and incorporated into the previously collected data and analyzed periodically. The data must be stored and retrieved easily and economically. A variety of codes can be used that simplify data handling. Manual systems are satisfactory for small herds, but, as herds become larger, the computer becomes necessary to minimize the number of errors and to obtain rapid analysis of the data. The most important aspect of the analysis of the data is the selection of the most useful indices or parameters that are required to monitor performance accurately. Following analysis of the data, reports containing useful information and recommendations are prepared and sent to the farmer.

Some studies have found that veterinary practitioners had difficulty motivating farmers to adopt herd health schemes

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in part because they were unable to demonstrate the financial advantages. Being able to demonstrate the current herd performance and the potential financial advantages of herd health schemes to farmers before they will take them up requires a certain amount of data on which to base the analyses. Sampling the data from 40 cows from large commercial herds (about 200 cows) and 20 cows from smaller herds (about 100 cows) allows the cost of poor performance to be estimated sufficiently accurately to determine whether further computer-assisted investigation is warranted (Chamberlain and Wassell, 1995).

Periodic Reports to the Producer

Regular reports must be prepared and sent to the producer. The reports are provided after each visit. Portable laptop computers now provide the opportunity for veterinarians to prepare a report directly on the farm during the visit. The number of reports depends on how frequently the veterinarian visits the herd as part of a herd health program. The reports contain the following types of information:

- A list of clinical examinations and treatments carried out as a record of events.
- An updated list of the individual animals, or groups of animals, depending on how they are handled in the particular program. This list includes all data relating to the disease, reproductive performance, and preventive procedures for the unit; it also enables each animal's (or group's) history for the immediate past to be reviewed. A lifetime history also is available on request for producers who require this information to make decisions on culling and to provide a health and production record at the time of sale.
- An analysis of the parameters used to evaluate reproductive efficiency and the waste caused by mastitis and other diseases. This is accompanied by the levels of performance proposed as targets and provides an opportunity for the veterinarian to comment on whether performance is good or suboptimal. It is important that sufficient flexibility be retained when assessing changes in performance indices. For example, with bulk milk somatic cell counts (SCCs), which fluctuate significantly from month to month, it is usual to wait until a 3-month rolling average continues at a high level before raising an alarm.
- Recommended actions. These are recommendations arising from other programmed reminders for that particular time of the year or reproductive cycle, or from the interactive part of the computer program. Based on the data that have already been provided to it, the computer identifies those cows that have had a poor reproductive performance, a poor production record, or serious disease incidents. These cows can be considered with a view to culling some of them. Similarly, the computer can identify the cows to be dried off and the dates on which this should be done, cows to be bred, and cows to be examined for pregnancy or abnormal reproductive function.
- Predicted production events. This is a developing and vital segment of the program. The producer can preplan a calving or reproductive pattern for the herd or flock. Armed with a knowledge of the reproductive performance status of the herd, the computer program can then advise when individual cows should be bred to conform with this pattern. Similarly, it is then possible, knowing the reproductive data, to predict what the milk production will be at particular times and to predict the feed requirements week by week. All of these functions are performed by modern programs. Producers receiving this advice can plan their feed program 6 months in advance. This gives them time to plant a crop, boost pastures with nitrogen fertilizers, acquire more land, and cull more cows.
- Cash flow predictions. These may also be included. An annual report may be prepared as a retrospective summation of the other reports that have already been provided for the year. This is the opportunity for a major review of the performance of the herd for the year and for an interherd comparison for a local group, with an annual meeting of participants to discuss progress and performance. The annual review of the herd needs to be done in conjunction with an updating of the herd profile.

General Advice

This is advice that does not originate from the monitoring program. It relates primarily to those actions that the producer must take regularly during the year. The action is generally directed at the prevention of specific diseases and the maintenance of production. Some of the actions are stimulated by events in the reproductive cycle. For example, cattle may need to be vaccinated for certain infectious diseases before breeding, ewes may need to be vaccinated for enterotoxemia in late pregnancy, and cows that are susceptible to milk fever need to be treated prophylactically close to the day of calving or need to have their diet formulated to minimize the disease.

The range of the recommendations is not universal for every farm and depends on the prevalence of disease in the individual herd and in the area. What veterinarians recommend depends on their knowledge of these matters and on their expectations of bad seasons or bad years of particular diseases, often according to the climate and the availability of feed. Also, the recommendations are affected by the need to remain cost-effective. For example, it may be financially more beneficial on some farms, in some years, to restrict the supplementary feeding of ewes, normally done to avoid pregnancy toxemia, because the expected prevalence may not warrant the additional expense.

The general advice just described can be sent by electronic mail at strategic times of the year, without the necessity of visiting the farm. In addition, a formal report along new information and techniques may be included and in the form of a newsletter to the veterinarian's clients.

COMPONENTS OF A HERD HEALTH MANAGEMENT PROGRAM

The components of a program include regularly scheduled farm visits by the veterinarian, good farm management by the producer, the recording and analysis of animal health and production data, and the provision and coordination of advice by the veterinarian. There must be a long-term commitment to continuous improvement to reduce unnecessary variations in production. The management styles of the producer and the veterinarian must include systems thinking and innovation, and there must be a vision of the future. All efforts must be directed toward the goals of the producer.

The success of the program depends on the competence of the veterinarian, the level of management of the producer, the reliability and adequacy of the records, and the competence with which the veterinarian provides advice and follows up the results of that advice. The veterinarian must become involved in analyses of the costs of production, income statements, and a breakdown of production costs (Marsh, 1999). A major determinant is the extent to which the producer complies with the advice of the veterinarian and adopts the recommendations of the veterinarian.

The veterinarian should identify the objectives of the producer before beginning a program. A clear picture of the production objectives, compared with actual performance, often identifies the presence of problems that have interfered with performance.

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The initial stages of any program should concentrate on solving obvious disease or production problems for which there are some obvious and reliable solutions. When these problems are resolved, attention can then be given to evaluating the health and production status of the herd and to the identification of other economically significant problems. Gradually, over a period of 2 to 5 years, the veterinarian becomes acquainted with the herd and its characteristics and areas where additional effort should be directed to improve health and production. It is a gradual, evolutionary process.

The continuous improvement of health and production of a livestock herd requires planning, implementation, and evaluation, and it is an ever present challenge to the veterinarian. Some principles need to be followed that are generally applicable to most situations. The Shewhart Cycle has been recommended as a set of guidelines for continuous improvement of food animal practice (Humble, 1995b). It is also known as the Plan-Do-Study-Act (PDSA) Cycle and is an adaptation of the scientific method; the cycle provides a means of planned experimentation for problem-solving and continuous improvement of products or processes. The cycle is used to increase knowledge about a product, process, or service and to provide a systematic way of accomplishing change. There are five stages:

Stage 1: Generation of an idea. Someone has an idea about improving a health management strategy. It may be for improving calf health, control of mastitis, weaning of calves, or control of any endemic disease in a herd.

Stage 2: A plan. All known variables are considered and a decision is made about what will be compared, tested, or studied. Animal health consultants, livestock producers, farm managers, and employees should meet to review everything known about variables and confounding factors. All employees can be useful to the process, and they should be asked to contribute thoughts and ideas during the planning stage. This stage can serve as the basis for establishing a team approach for problem solving. The goal is continuous improvement.

Stage 3: The "do stage." In this stage, the test, the comparison, or trial is performed, preferably on a small scale. Management must ensure that the procedures outlined in the plan are performed correctly.

Stage 4: The information is collected and analyzed. Did the test or trial go as planned? What was learned? What do the data indicate? Were there improvements in performance? What problems were encountered? What unexpected variables were encountered during the trial? Is it possible to elucidate more important variables that contribute to performance? Was anything learned about people and teamwork? Which individuals contributed most to understanding the problems encountered during the study? Effective feedback from all people involved is crucial (Palazzolo, 1997).

Stage 5: Acting on the information. Three decisions can be made. First, adopt the change. Second, abandon the idea and start over. Third, modify the plan and run the trial or test under slightly different conditions.

Frequency of Visits to the Herd

The most common aspect of any herd health program is the regularly scheduled visit to the herd or flock. The frequency of visits depends on the class of livestock, the size of the herd, the prevalence of disease, the existence of particular disease problems, the level of risk aversion of the producer, and the length of time the herd has been on a program. Monthly visits are common for year-round calving dairy herds with fewer than 100 cows. Weekly visits become necessary for large herds. For large dairy herds, some veterinarians travel long distances to get to the farm and then spend long periods working through the various aspects of the herd. Four yearly visits are common for commercial beef herds, and weekly or daily visits are usually necessary for beef feedlots with a total capacity of 5000 or more head. For 100-sow, farrow-finish swine herds, monthly visits are common.

The traditional practice of regularly scheduled visits to the herd is becoming inadequate for some herds. Once a veterinarian becomes involved with the health management of a herd, it may be necessary to visit the herd as often as required to initiate and complete certain strategies and tasks. This means that veterinarians should direct the animal health and production management programs and visit the farm as often as necessary to achieve the level of animal health and production desired. When disease or production problems occur, it is the responsibility of the veterinarian to visit the herd as often as necessary until the problem is resolved. This may be followed by less frequent visits to the herd and by telephone contacts with the owner to ensure that the problem has been resolved and that progress toward optimum health is being made. Failure of the veterinarian to maintain contact with the owner concerning health and production problems has been a weakness in some health management programs. Veterinarians must show producers that they are concerned about the health and production of the herds for which they provide veterinary service.

Activities During the Farm Visit

The veterinary activities conducted during each visit are similar for each species or class of livestock, but the specific activities vary according to the class of livestock, the season of the year, and the length of time the herd has been on the program.

The primary purpose of the farm visit is to organize and concentrate the veterinary activities into a regular schedule to ensure that they get done. There are several animal health and production activities that occur during the production cycle of each animal. A major objective of the visit is to determine the actual performance of animal health and production, compare it with targets of performance and farm goals, and decide which performance index is abnormal. The veterinarian then attempts to determine the cause(s) of the shortfalls in health status or production and formulate cost-effective corrective action (see Fig. 1-1). The regularly scheduled farm visit is also part of a surveillance system designed to detect or predict animal health and production problems before they become economically significant and to indicate the corrective action necessary. Under ideal conditions, each visit should provide a summary of the animal health and production status, the reasons for failure to achieve certain targets of performance, and recommendations for corrective action. For some parameters of performance, the data are available directly from the records or from the computer printout of the DHIA services in the case of the dairy herds enrolled in such milk recording and herd performance monitoring programs. Examples include milk production per cow, SCC, butterfat and protein percentage in milk, average number of pigs born alive per sow, and average number of pigs weaned per litter. In a beef feedlot, for example, with a computerized animal health and production monitoring system, the computer provides daily summaries of morbidity, mortality, treatment response, and number of repeat treatments, and it identifies pens of animals that are on the verge of an epidemic of acute undifferentiated respiratory disease that should be examined more closely. For other parameters, the veterinarian has to carry out certain

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diagnostic procedures, such as pregnancy diagnosis, to obtain the information.

Some examples of specific farm visit activities follow.

Surveillance of Reproductive Performance

In breeding herds, a major emphasis is on surveillance of reproductive performance. For example, in dairy herds, which calve year-round, at each monthly visit all cows bred more than 35 days earlier are examined for pregnancy by rectal examination. The cows to be examined are identified by review of the individual cow records or by the use of a computer. Regular pregnancy examinations can identify nonpregnant cows as soon as possible so that early intervention can be taken. In dairy herds, prospective serology and analysis have been used in the diagnosis of abortion on a herd basis (Thurmond et al, 1990). In beef breeding herds, the bulls are examined for breeding soundness before the breeding season begins. Pregnancy examinations are performed only once annually, preferably in early pregnancy and usually following a short breeding season of 42 to 60 days. In swine herds, reproductive performance may be monitored regularly by pregnancy examination through the use of an ultrasound pregnancy tester, monitoring of the number of sows that return to heat 3 weeks after breeding, and the number of pigs born alive per litter. Similarly, sheep can be examined for pregnancy through the use of an ultrasound pregnancy tester and decisions made about feeds and feeding throughout the remainder of pregnancy to minimize the incidence of pregnancy toxemia and to ensure a high survival rate of lambs.

Monitoring and Analysis of Production Performance

The production of livestock and their products can be monitored on a continuous basis and the data used as indicators of performance. The parameters include average daily milk production, butterfat test, average daily body weight gain in feedlot cattle, closeout financial data in feedlot pens, days to reach market weight in pigs, feed efficiency in feedlot cattle and finishing pigs, and grades of carcasses at slaughter. The causes of culling, especially in dairy herds, is an important part of the evaluation of herd performance and the major causes of economic losses (Esslemont and Kossaibati, 1997). More details of monitoring are presented in Chapter 3.

Breeding Programs and Genetic Selection

Some veterinarians have become involved in providing regular advice on breeding programs and the selection of breeding stock in dairy herds, beef breeding herds, swine herds, and sheep flocks. This requires the development of expertise in pedigree analysis and the monitoring of performance indices. These activities are enhanced with computer technology. Chapter 8 deals with the role of the veterinarian in culling and genetics in dairy cattle herds.

Monitoring of Nutritional Status

The feeds and feeding program have a major influence on reproductive performance, growth rate, and milk production and must be monitored regularly. The veterinarian must be aware of any changes in the feeding program that have occurred since the last farm visit or that are intended in the near future. On breeding farms, there are several different age groups of animals at different levels of growth and production. This requires close surveillance to avoid undernutrition or overnutrition. Scoring of the body condition of dairy cattle, beef cows, sheep, and swine is becoming commonplace as an indicator of the adequacy of the diet. Veterinary clinical nutrition is now a veterinary medical specialty that should provide new and useful information for the practitioner working with a particular species or class of food animals (Remillard and Thatcher, 1988). The American College of Veterinary Nutrition also provides consultants in veterinary nutrition who can be called on for advice in solving nutritional problems. An experienced and competent nutritionist should be consulted to assist with complex nutritional problems.

Clinical and Pathologic Examination of Animals

On a herd basis, there are usually some animals affected with clinical disease that the farmer has identified. They should be examined and the necessary laboratory samples taken to obtain a definitive, causative diagnosis. In beef feedlots and swine herds, necropsy examination of animals that have died naturally or in selected clinical cases is a common practice in order to obtain a diagnosis. Necropsy information is an integral component for monitoring feedlot disease and designing rational preventive and therapeutic feedlot animal health strategies.

Computer imaging technology using a digital video camera can be used to facilitate the capture of feedlot necropsy data (Wildman et al, 2000). A trained technician follows a written protocol for prosection of each dead animal, capturing necropsy images as appropriate. The images are electronically transferred to a central site for veterinary interpretation and diagnosis. The veterinarian generates a necropsy report and transfers it to the originating feedlot to update the computerized animal health record-keeping system. Comparison of the necropsy diagnosis made by a field veterinarian with the diagnosis made by two veterinarians in the office receiving the images found that the digital necropsy images agreed with the gold standard diagnosis, on average, 95% of the time. When disagreement occurred between the off-site and on-site diagnoses, it was related to image quality rather than interpretation of the gross findings. The images are stored temporarily on an office server and are archived periodically to CD-ROM for permanent storage.

Analysis of Disease Occurrence

The records of all clinical diseases that have occurred since the last visit should be examined. The diagnosis, course of the disease, morbidity and case-fatality rates, treatments used, and response rates should be determined. The veterinarian should attempt to determine the cause or risk factors retrospectively from the evidence available and to prescribe advice on the treatment and control of future cases. This includes identification of risk factors that may have contributed to the disease.

In swine herds, producers may be unable to discriminate accurately between stillbirths and dying soon after birth. Without validation of data-recording accuracy, retrospective and prospective studies using producer diagnoses of causes of death in suckling pigs are likely to be invalid (Vaillancourt et al, 1990).

In dairy herds, the effects of the major health problems on the length of productive life, defined as the number of days between date of first calving and date at culling or death, has been used as a suitable measure of longevity (Beaudeau et al, 1995). The probability of a cow being culled increased in early and late stages of lactation in older cows, in low-producing cows, and in cows with poor reproduction performance. Mastitis before the peak of lactation or during the dry period increased the risk. Teat injuries and

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nontraumatic udder diseases had a large influence on longevity. These survival analysis techniques offer dairy farmers intuitive tools to predict length of productive life that may help them make culling decisions (Beaudeau et al, 1995).

Mass screening of livestock sera can be used for monitoring antibodies against infectious diseases (Behymer et al, 1991).

Routine Elective Activities

In some programs, veterinarians perform certain routine activities at strategic times. These include vaccination, administration of anthelmintics, aborting feedlot heifers, dehorning, castration, foot trimming, and other minor surgical procedures, such as spaying beef heifers. If veterinarians are not performing these procedures, they should at least be aware of when and how they are being performed. However, many producers prefer to employ their veterinarian for these tasks, which provides an excellent opportunity to get on the farm and make observations about the performance of the herd.

Examination and Discussion of Records and Reports

All production and disease reports, and relevant marketing and economic information, should be interpreted and recommendations made for corrective action, if necessary. The results of the previous herd health visit should be discussed with the farmer. The results of recommendations made on previous visits should be assessed and changes made. This requires that the veterinarian bring to the farm a current client file that contains the results of herd health visits, necropsy reports, feed analysis reports, and recommendations that were made for the previous few months. The information may be readily available in summary form on the on-farm computer. There are always some problems with the accuracy and completeness of the records, and these should be corrected each month.

Emergency Farm Visits

Emergency farm visits are independent of the programmed visits. However, the nature and amount of emergency veterinary medicine necessary in the herd are relevant to the overall herd health program. Every disease incident treated by the farmer or the veterinarian should be recorded. At each farm visit, the diagnosis, treatment, and control of the diseases encountered are discussed. As producers treat a greater percentage of the commonly occurring, easily recognizable diseases, the veterinarian is called to the more difficult cases for which the diagnosis is not obvious or that did not respond to therapy given by the producer. These require increasing emphasis on a careful and thorough clinical examination, making a rapid and accurate clinical diagnosis, and providing recommendations for treatment or slaughter for salvage. In some cases, euthanasia and necropsy may be indicated in order to arrive at a diagnosis.

Investigation of Outbreaks of Disease and Crisis Management

Outbreaks of disease should be investigated as soon as possible by means of a carefully planned clinical and epidemiological examination of the herd (Hancock et al, 1988). The investigation should include the clinical examination of affected animals and the submission of appropriate laboratory samples (Lessard, 1988). Detailed recommendations for treatment and control should be reported in writing to the farmer and a copy of the report retained by the veterinarian for future reference. Many veterinarians have not been proficient in this aspect of herd medicine. Some reasons include allowing a busy schedule of emergency visits that seem to take up much or all of the time (thus not leaving any time to do the herd investigation) and the frustrations of the detail and rigor of a proper disease investigation on a herd basis. However, if veterinarians take an interest in the problem and consult with specialists from diagnostic laboratories, universities, and industry, such field investigations can be rewarding, new insights into health and production can be discovered, and problems can be solved. Producers then are willing to invest the costs involved. It is imperative that the veterinarian provide a detailed report of the investigation that explains the problem, present the clinical and laboratory findings, explain the risk factors that were involved, and outline how the problem can be controlled or minimized in the future. Details of herd investigations are outlined in Chapter 5.

Consultation by Telephone

A significant amount of consultation can be done by telephone and may consume a large amount of the veterinarian's time. Many practitioners now have telephones in their vehicles, through which they can be contacted by producers who wish to ask a question about a clinical case or a herd problem. Such communication should be encouraged. Producers must not be reluctant to telephone their veterinarian to discuss a problem. Recommendations for the treatment and control of herd problems may be given over the telephone, provided that veterinarians are confident they have sufficient knowledge about the particular problem from previous visits to the farm. However, all major recommendations should be recorded and followed by a written report to the farmer. This is particularly important when prescriptions for mass medication of feed and water are given by telephone. A computer equipped with a modem can be used by practitioners to access information from large databases and to send information and recommendations to producers. Effective communication and presentation of information in a format that the producer can understand are vital.

Meetings with Participating Producers

A valuable aspect of any health management veterinary service is the convening of regular meetings of participating producers, either individually or in groups, to discuss the results of performance of the herds. Actual farm records of animal health and production can be presented anonymously, and individual producers can compare their performance indices with those of others in the anonymous group. The high levels of performance can be used as targets of performance that are possible under local conditions. This should provide a stimulus to producers with suboptimal levels of performance to establish farm goals and to explore methods of improving performance in their herds. Meetings must be planned carefully with clear objectives. Veterinarians providing service to large livestock operations now meet regularly with the farm staff to discuss health and production problems.

Many practices are now sponsoring extension education programs for their clients. Typically, a few extension type meetings of several hours in length will be held annually. Invited specialists will present lectures and demonstrations on topics such as housing and handling facilities for dairy herds, lameness in dairy cows, policies for culling dairy cows, calf health, record keeping systems, uses of antibiotics and pharmaceuticals in swine herds, vaccination programs for dairy and beef cattle herds, mastitis control, and breeding programs and calving management in beef cattle herds.

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The more knowledgeable producers become about the science of health and production management, the more they will consult with their veterinarian.

Provision of Drugs and Vaccines

Drugs and vaccines to be used in the herd are commonly supplied by the veterinary practice. Some practices supply the products at a reduced gross margin of profit as part of the health management program. This may encourage the producer to purchase the supplies from the veterinarian, who can provide recommendations for their use and is also then aware of the drugs and vaccines being used in the herd. The ethical marketing of drugs to livestock producers is a controversial subject (Upham, 1993). Some veterinarians actively promote the sale of drugs and others do not. Those who are involved assume the liability associated with their use. In some jurisdictions, the veterinary act stipulates that a veterinary-client relationship must be established before the veterinarian dispenses drugs to a livestock producer. This means that the veterinarian must have first-hand knowledge of the herd and the animals that are being treated.

Drug Residue Avoidance

Residues of therapeutic and production-enhancing drugs in meat and milk and other animal by-products derived from domestic animals are now a topic of considerable concern in all aspects of the food-producing animal industry. Producers and the national organizations that represent them are being confronted by consumers who are increasingly aware of the potential for drug residues in meat and milk. Veterinarians are also facing a dramatic change in attitude and behavior concerning drug residues as a result of the therapeutic and prophylactic use of drugs. Until recently, veterinarians did not pay sufficient attention to ensuring that the producer adhered strictly to the withdrawal period for milk and meat from animals treated with a variety of drugs. The dominant cause of drug residues is failure to observe withholding times. Veterinarians have a major responsibility to ensure that their producer-clients are aware of the regulations regarding the use of drugs in food-producing animals. Each drug used in a species or class of animals must have been approved for use by the agency responsible for such approval. Use of the drug at a dose higher than approved or in a species not approved constitutes *extra-label use*, which requires special considerations. The Food Animal Residue Avoidance Databank (FARAD) is a computerized database that compiles information into one source on veterinary drugs used in livestock production (Sundlof et al, 1986). This can be used to obtain information on the pharmacokinetics of drugs, the regulatory information on tolerance and legal levels of chemical residues in animal products, and the allowable concentrations of drugs in the feed. The objective of FARAD is to reduce the incidence of residues in animal products by educational methods rather than by regulations alone.

A 2-year investigation of dairy farms by the U.S. General Accounting Office pertaining to the nation's milk supply found a total of 82 drugs known or believed to be used to treat lactating dairy cows on dairy farms. Of the 82 drugs, 52 were not approved for use in lactating dairy cows, and 33 of the 52 were not approved for use in food animal species. A national survey of veterinarian-initiated drug use in lactating dairy cows in the United States found that drugs used or prescribed most to treat lactating dairy cows are antibiotics, followed by antiinflammatory drugs and tranquilizer or analgesic drugs (Sundlof et al, 1995). Next to antimicrobials and xylazine, the nonsteroidal antiinflammatory drugs (NSAIDs) were prescribed most frequently by dairy practitioners. The survey indicates that the majority of unapproved drugs prescribed by veterinarians are nonsteroidal antiinflammatories and analgesics or tranquilizers, all of which are intended for humane purposes to reduce pain.

In a study performed by the Food Safety Inspection Service Residue Violation Information System of violative chemical residues in U.S. beef from 1991 to 1993, most of the animals found to have violative residues were bob calves and culled cows. In bob calves, neomycin was the most frequently identified violative chemical, followed by tetracycline, gentamicin, oxytetracycline, and penicillin. In culled cows, penicillin was the most frequently identified violative chemical and was found most frequently in combination with other chemicals in cows with multiple violative residues (Gibbons et al, 1996).

Animal Welfare and Animal Rights

Animal welfare became an important veterinary issue in the late twentieth century. For many years, the goals of livestock production have been increased total production by genetic and environmental means and increased efficiency of production, especially in terms of labor and space. However, the use of animals for the intensive production of meat, milk, and wool has spawned concern in the minds of some people (Swanson, 1995). There has been increasing interest in and concern about the welfare of animals used for agricultural production. This growing concern has been mainly in evidence in the higher income countries and has been linked very closely to the public image of "factory farming" involving animals kept in confined conditions. Concerns about farm animal welfare vary widely between individuals, across societies, and over time. Within the European Union, there is increasing debate about the need for further legislation to safeguard the welfare of farm animals (Spedding, 1994). The importance of animal welfare in Europe is illustrated by the participation of all European Community member states as contracting parties to the Council of Europe Convention for the Protection of Animals Kept for Farming Purposes (Spedding, 1994). Consideration of farm animal welfare has been incorporated explicitly into European Union agricultural policy along with environmental considerations that state the need to "preserve and improve the natural environment and animal welfare by preventing undesirable intensive farming." Far-reaching legislation concerning food animal production has been passed, much of it clearly giving value to the animal's perceived quality of life, even if it means subordinating requirements for efficiency of production (Crook and Heider, 1994). In the United States, there is evidence of a growing awareness and concern about farm animal welfare issues similar to that experienced in the northern countries of the European Union and Scandinavia. Contingent valuation or the willingness of people to pay to support developments intended to improve the welfare of farm animals has been explored (Bennett and Larson, 1996).

Animal welfare advocates are concerned about the well being and comfort of food-producing animals. Animal rights activists believe that animals have the same rights as humans and should not be used as food-producing animals.

A major overall concern of animal welfare interest groups is the humaneness of intensive animal production, in which animals are kept under confined, high-stocking-density conditions. They object to animals' having no opportunity for exercise and being fed high-nutrient diets so that they can grow quickly and efficiently and reach market weight in the shortest time possible. Although intensive livestock production is perceived as being stressful to the animals

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involved, there is little documented scientific evidence to support this belief. In fact, there is a strong case to be made for the association of optimum animal production with good animal welfare principles. Some activists believe that intensive livestock production is associated with an increase in the incidence of infectious diseases. There is concern about how veal calves are housed in individual stalls and fed milk, with no access to roughage. The well being of gilts and sows tethered in individual stalls or crates with no access to exercise is questioned. Individual sow crates probably will be banned in certain countries in the near future. This subject is presented and discussed in more detail in Chapter 15 ("Swine Health Management"). The veterinary profession has been remarkably inactive in the field of animal welfare. This is ironic and unfortunate because the promotion of improved health (a major welfare consideration) is the greatest single contribution that veterinarians can make in livestock production. The reluctance of the profession to address the concerns of humane societies has impeded progress toward a greater understanding of animal welfare issues, as has its ability to communicate the positive welfare implications of veterinary contributions to reduced animal disease and stress. Clearly, a reassessment of attitudes toward manipulation of animals for human use is necessary (Murray and Ward, 1993).

Some countries have established codes of welfare for farm animals, which define acceptable standards of welfare in terms of the five freedoms: freedom from malnutrition; freedom from thermal or physical discomfort; freedom from injury and disease; freedom to express most normal, socially acceptable patterns of behavior; and freedom from fear (Webster, 1987). Agriculture Canada has published recommended codes of practice for the care and handling of specially fed veal calves, of beef cattle, and of pigs. In other cases professional and industry groups are also taking the initiative to develop codes of welfare for their animals.

A distinction must be made between "positive welfare," which is the aim of the Farm Animal Welfare Council, and the avoidance of cruelty, which is illegal. "Positive welfare" for the Farm Animal Welfare Council is based on trying to achieve the "five freedoms" for farmed animals. Public feelings about cruelty certainly would be much stronger than feelings about failure to achieve all five freedoms. The food animal veterinary practitioner is considered by those outside of the profession as the ultimate advocate for animal well being. This position requires that practitioners provide leadership in the development and implementation of acceptable humane standards in farm animal agriculture (AVMA at Work, 1994).

Farm animal welfare problems arise during handling, transport, and slaughter of livestock (Grandin, 1994). The single most important factor that determines how animals are handled is management attitude. Operations with humane livestock handling almost always have a manager who insists on humane handling, and operations with poor handling almost always have lax management or a manager who actually participates in animal abuse. Animal handling in feedlots and packing plants has improved in the past 15 years. Rough handling is the most important welfare problem and is a major cause of injuries, bruises, and stress. Handlers and managers need to learn livestock behavior principles so they can move animals quietly and efficiently. The maintenance of high handling standards requires sustained management commitment to continual incremental improvement of procedures. The transportation of animals from the farm to the slaughter plant must be accomplished with consideration of factors such as preventing stress during loading and unloading, avoiding overloading, and providing rest and feed stops at regular intervals for long trips (Grandin, 1994).

Nonambulatory (downer) cattle are a major problem, and veterinarians must provide leadership in the handling of such animals. In most jurisdictions legislation exists involving the handling and disposition of downer animals (Grandin, 1994).

It behooves veterinarians who provide health management services to livestock producers to be aware of the animal welfare aspects of the production process and to incorporate management changes that can meet the welfare standards being developed. Veterinarians should feel morally obliged to make livestock producers aware of infringements of practices of acceptable animal welfare. Veterinary colleges are now including animal ethology in the curriculum, ethologists are being appointed to faculty positions at universities, and research projects in animal behavior designed to answer some of the questions about intensive livestock production are under way. The intensive production systems in which livestock are being raised have provoked both scientific and public debate. Definitions of animal welfare/well being are not precise and will continue to evolve based on social and scientific information (Swanson, 1995).

Prevention of Zoonoses

The prevention of zoonoses (infectious diseases of animals transmissible to humans) is a responsibility of the veterinarian. There are well-known zoonoses that occur in each of the domesticated food-producing animal species. Over 150 zoonoses are recognized worldwide, with at least 40 having significance as occupational diseases in animal agriculture (Donham, 1985). In addition to direct human health disease, agricultural zoonoses are a major economic drain on the animal protein industry. Zoonoses are less common in developed countries, where there is improved nutrition, improved public health measures, and better environmental sanitation. Zoonoses are often not diagnosed or are misdiagnosed because the clinical signs are not pathognomonic. Also, there is a lack of awareness among physicians regarding the occurrence of the zoonoses.

High-risk groups for the zoonoses are those that have greater than average contact with animals, including farm workers, abattoir workers, veterinarians, and visitors to farms. Visitors to dairy farms should not be allowed to drink the raw milk from the bulk tank because of the risk of infectious disease. In some instances the zoonotic disease occurs in an animal and the infection spreads to humans on the farm or is transferred by the milk or meat to consumers at large. In other situations animals are inapparent carriers of infections and pose a health hazard for humans. For example, infectious agents such as *E. coli* 0157:H7 do not usually cause clinical disease in carrier cattle but may infect humans following the ingestion of inadequately cooked ground beef contaminated with the organism. The veterinarian must be aware of the occurrence of these infections and alert members of the farm family of the potential for human infection, which requires appropriate preventive precautions.

Foodborne diseases such as salmonellosis and campylobacteriosis from beef and poultry, beef tapeworm, toxoplasmosis from pork, and trichinosis constitute a major public health concern. In addition to illnesses and deaths, they account for the loss of billions of dollars annually in lost productivity because of absenteeism from work. Control of these diseases is becoming a significant activity for veterinarians providing health management services and for those in meat inspection. Reducing the incidence of these diseases requires an effective public health education program, the establishment of regulations requiring pathogen-free animal

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feeds, and the adoption of industry production standards designed to reduce the risk of infection to unwary consumers. Veterinarians should consult with public health officials when agricultural zoonoses are suspected on livestock farms with which they work.

Bovine Spongiform Encephalopathy

The recognition of BSE in England in 1985 and the potential risk that the beef could be the source of the agent causing variant Creutzfeldt-Jakob (vCJD) disease in humans was one of the most important zoonotic concerns in many years (Bruce et al, 1997) There is evidence that the biological and molecular transmission characteristics of vCJD are consistent with it being the human counterpart of BSE (Hill et al, 1997; Phillips, 2000).

Environmental Toxicology and Ecosystem Health

Environmental toxicology encompasses the study of a wide array of chemical contaminants and toxic effects on species ranging from humans to other vertebrates, invertebrates, plants, protozoa, bacteria, fungi, and viruses (Beasley, 1993). Ecotoxicology, a subdiscipline of environmental toxicology, is the science of toxicants in environments and their effects on living organisms, including interactions among organisms and with the environment.

Ecosystem health aims to provide a suitable environment to support human populations and maintain biological diversity. The goals of ecosystem health practitioners are often achieved through the equivalent of health management programs. Monitoring ecosystem health by using parameters currently used by classic ecologists, as well as those of conservation biologists, veterinarians, plant health specialists, geneticists, and others, will be essential to prevent problems before they become widespread. As in the production paradigm of food animal health management, conserving inputs and providing what is needed for optimum health is the ideal mode for ecosystem health management. It will also be necessary to include various types of emergency specialists able to deal with such problems as chemical spills, exotic species invasions, exotic diseases, and problems facing threatened and endangered species. Food animal practitioners are now becoming involved in improved productivity and wholesomeness of food of animal origin through better air and water quality, nutritious diets free from harmful contaminants, proper disposal of animal wastes, and specific disease-monitoring and prevention programs. Because food animal practitioners provide regular on-the-farm consultation, which increasingly involves management decisions, and because of their knowledge of infectious agents and toxic chemicals, they already assume a role in farm ecosystem protection. As agricultural policy becomes more attuned to environmental concerns, and as concerns with regard to urban, suburban, and home environments increase, at least some astute veterinarians will expand on their current expertise as knowledgeable environmental consultants for the animal-owning public. Concerns for environmental health may focus on the needs of the human population, domestic animals, and wildlife and may involve recommendations to avoid contamination of air, soil, water, and food. Environmental assessments will be performed on farm visits.

Veterinarians are now becoming involved in evaluating the potential adverse effects of environmental pollution on livestock and human health. Only recently have epidemiologic methods been used to study the potential effects of environmental contaminants from the oil and natural gas industry on livestock health and production (Waldner et al, 1998).

Food Safety

Foodborne diseases are an important public health threat internationally and nationally (Angulo, 1996). It is estimated that annually in the United States, 6 to 81 million persons become ill and 9000 die from foodborne disease. The epidemiologic characteristics of foodborne diseases in the United States are also changing. In recent years, several large multistate epidemics have occurred, caused by newly recognized pathogens including *E. coli* 0157:H7, *Listeria* sp. and *Salmonella enteritidis* (Potter, 1992). Some of these events are associated with changes in food processing from the "farm to the fork." When prepared properly foods derived from animal products are generally safe and wholesome. The federal and state departments of agriculture inspect and test animal products to help ensure that only wholesome, safe foods reach the consumer. As a result, meat and milk are among the safest and most wholesome food products that consumers can purchase. However, despite the combined efforts of people and nature to protect the food chain, microbial and chemical agents occasionally find their way into animal products (McCapes et al, 1991).

As a result of the emerging diseases just mentioned, food production, processing, and marketing increasingly are being influenced by concerns for consumer health (Heidelbaugh and Menning, 1993). There are increasing demands for reliable trace-back of food from consumer to producer, coupled with appropriate liability for consumer health. There are concerns for the costs of primary health care of ill patients and the lack of efficient use of health management of food-producing animals. The evolving human population is aging and more susceptible to foodborne diseases. The general population is increasingly aware that failure to provide safe food may be a general failure of government rules and regulations. Also, the potential for chemical residues in meat is a consumer concern that must be addressed. As a result, producers, through associations such as the National Cattlemen's Beef Association, the National Pork Producer's Council, and the National Milk Producer's Federation, have been urging expansion of stringent "on-the-farm" quality assurance initiatives and programs (Teske, 1992). The proper and responsible use of animal drugs and feed additives in food animals will continue to be an important issue for consumers and therefore all those involved directly or indirectly in animal agriculture enterprises. The perception by the general public that the food-animal industry is highly profit oriented creates considerable distrust in the system of food safety already in place. The expansion of international trade in food products intensifies the need for harmonization of food safety standards (Crawford, 1992b). The shortage of veterinarians who are qualified in modern food safety programs and management and the unwillingness or inability of veterinary colleges to prepare or inspire their students to pursue a career in food safety slow progress in the specialty.

Historically, veterinary medicine has provided national leadership for assurance of a plentiful supply of safe and wholesome foods of animal origin. Veterinary medical education and training provide the basis for this leadership and give the veterinary profession the unique ability to effectively participate in the full spectrum of activities involved in the production and consumption of foods of animal origin. These activities include live animal production, slaughter, processing, distribution, preparation, and consumption (McCapes et al, 1991). New developments in biotechnology will be used in food safety programs (Kopchick, 1992; Headon, 1994). New diagnostic techniques are now available that reduce the time necessary to identify food pathogens and their sources. Recombinant DNA technology

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may enable the development of recombinant proteins such as insulin, growth hormone, interferon, and recombinant vaccines. In the future, genetic modification of food-producing animals may allow modification of animal products to meet the consumer needs for healthy and safe food. Appropriate recombinant technologies may allow modification of animal products to better fit consumer needs for healthy and safe food. Current technologies used in animal production that modify or repartition animal growth yield leaner meat products with less fat. With emerging biotechnologies similar options will become available for beef and pork products. The generation of these types of animal products will require gene mapping and selective breeding, and the production of transgenic animals.

A symposium on food safety in 1995 presented the preharvest and postharvest food safety issues and discussed how various groups are responding to the changing epidemiological characteristics of foodborne diseases. The roles of veterinarians in promoting the safety of foods of animal origin are changing and will become a major activity in health management.

Preharvest Activities

The USDA has been monitoring animal populations from the farm through marketing, transportation, and preslaughter or processing preparation. These preharvest activities include preslaughter practices, animal health and well being, stressors, environmental conditions, feed and water, and vectors. Identification of the risk factors in preharvest activities that may contribute to foodborne diseases enable veterinarians to recommend practices that will improve food safety. Food safety begins at the point of conception of food animals on the farm, achieves greater attention at birth, and receives constant monitoring to the point of delivery at the dock of the food processor.

Postharvest Activities

Postharvest food safety issues include slaughter, processing, distribution, retail, and preparation (Sparling, 1996). The most important food safety hazard associated with raw meat products is contamination with bacteria, primarily *Salmonella* and *Campylobacter* spp. and *E. coli* 0157:H7. During slaughter of cattle, removal of the hide causes some aerosol contamination of the surface of the carcass with fecal contaminants. Such contamination has resulted in major improvements in processing, such as steam vacuuming to reduce the bacterial count on the surface of carcasses. Controlling the multiplication of bacteria during storage, handling, and preparation of food is a complex challenge. The presence of *E. coli* 0157:H7 in ground beef is now considered a food adulterant in the United States.

The National Milk Producers Federation of the United States has stated that there are three major milk safety issues facing the dairy industry: antibiotic residues, extra-label use of animal drugs, and bovine somatotropin (Barr, 1992). The Federation has taken various steps to assure consumers of safe and wholesome dairy products. A test sample of each farmer's milk is taken before it leaves the farm. Before a truck unloads its tank of milk at the plant, the tanker is checked for milk color, odor, and appearance; proper refrigeration; acidity of the milk; bacteria count; and milkfat content. The milk is also tested for antibiotic residues. If the milk fails regulatory or company standards, the entire tanker of milk is rejected. Consumers and activists are demanding zero levels of residues in milk. The most effective way to reduce animal drug residues is to minimize the need for animal medication unless necessary. To do that, dairy farmers must use an effective health management program. Veterinarians have a vital role in outlining explicitly the health management and production strategies to treat and control infectious diseases. When lactating animals require treatment, farmers must observe the milk withdrawal period established by the jurisdiction responsible for drug use. The National Milk Producers Federation and the AVMA initiated joint efforts in 1988 to develop the Milk and Dairy Beef Residue Prevention Program. This is a 10-point quality assurance program to help dairy farmers and veterinarians work together to improve the health of dairy herds, reduce the need for animal medications, and further ensure the safety and wholesomeness of milk, milk products, and dairy beef. Food animal veterinarians are the first line of defense on food safety and are capable of making the informed decisions necessary to protect human food safety while providing comprehensive health management advice to owners of food-producing animals.

Disease Surveillance

The National Center for Infectious Diseases at the Center for Disease Control and Prevention (CDC) has developed strategies for responding to emerging infectious diseases, several of which are foodborne diseases. The strategic plan collaborates with state health departments and numerous professional organizations. The plan emphasizes the need for improved surveillance, applied research, increased prevention and control efforts, and strengthened public health infrastructure as the essential elements for responding to emerging infectious diseases.

Hazard Analysis Critical Control Points

Many food industries have established hazard analysis critical control points (HACCPs) programs to assure food safety (Stenholm and Waggoner, 1992). The HACCP programs involve identification and monitoring of critical points in the food manufacturing processes. These programs place responsibility on industry to meet food safety standards, reducing the demand for government oversight in the food industry operation and increasing the impact of each regulatory inspection. In 1995, the Food Safety and Inspection Service (FSIS) of the USDA proposed sweeping changes in the meat and poultry inspection system, based on the National Research Council (NRC) Report of the Committee on the Scientific Basis of the Nation's Meat and Poultry Inspection Program (National Research Council, 1985). Inspected plants would be required to use a HACCP system. The FSIS established, for the first time, food-safety performance standards for pathogenic microorganisms that slaughter plants must meet, including the requirement for plants to conduct daily microbial testing to verify that the standards are being met. The FSIS public health mandate requires that the plant also work with the animal production, food transportation, distribution, and retail sectors to implement effective strategies and to ensure that the whole food delivery system, from farm to table, is working effectively to prevent food safety problems (Cross, 1992). The FSIS believes that HACCP principles can be used to structure voluntary national animal health programs that focus on pathogen reduction.

Meat inspection procedures in the European Community are being evaluated for their effectiveness in providing quality meat (Berends et al, 1993). It is suggested that neither the current nor the proposed revisions of antemortem and postmortem meat inspection procedures alone are insufficient, and that only integrated approaches, applied to each step of animal and meat production, will lead to better quality meat.

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Food Safety in Veterinary Education

The public health importance of food safety has led to increased emphasis on food safety education in veterinary curricula and continuing education. There is a critical need for leadership capable of providing the public health-oriented management essential to food safety programs. The AVMA has made detailed recommendations to improve the safety of foods of animal origin (Heidelbaugh, 1992). Some veterinary colleges have established academic faculty chairs in food safety and veterinary public health (Crawford, 1992a). The veterinarian is the professional best prepared to provide the essential preventive medicine and public health oversight and integration of the many scientific disciplines essential to science-based programs for the safety of foods of animal origin (Heidelbaugh and Menning, 1993). The veterinarian can provide the essential preventive medical approach for food safety at all levels in the food-animal chain (farm, ranch, antemortem, postmortem, processing, distribution, and final preparation for consumption). Thus the veterinary profession has the responsibility to continue to provide specialty-educated veterinarians for their unique role in assuring the safety of foods of animal origin. The safety of foods of animal origin will continue to be important as technologies become more complex, international trade expands, restorative medicine costs increase, threats of foreign animal disease exacerbate, preventive medicine becomes more science based, risk assessment becomes increasingly the rationale for preventive measures, new diseases emerge, advances in molecular biology are implemented, environmental concerns intensify, and preventive medicine becomes the predominating form of medical science.

Antimicrobial Resistance in Food Animal Production and Public Health

A major question in the health management of food-producing animals is, "Does the use of antimicrobials in food animal production contribute to antimicrobial resistance in human medicine?"

Antimicrobials are used for the treatment and control of many economically important bacterial and protozoal infections of food-producing animals. They are also used as feed additives for growth promotion, which contributes to the economical production of wholesome beef and pork.

The various uses of antimicrobials in food-producing animals, especially in beef feedlot cattle and in swine herds, are presented in Chapters 4, 14, and 15.

Antimicrobial Residues in Food and Antimicrobial Resistance in Human Medicine

The potential risks from using antimicrobials in food producing animals are antimicrobial residues in meat and milk, and the emergence of antimicrobial-resistant enteric bacteria in animals that may be transferred to humans and cause clinical disease, which is difficult to treat because of antimicrobial resistance. Based on published information, there are no significant antimicrobial residues in beef that pose a human health hazard.

The problem of the increasing incidence of antimicrobial resistance in human medicine is commonly attributed to the subtherapeutic use of antimicrobials in the health and production management of food producing animals and to the overprescribing of antimicrobials by human physicians. The scientific medical literature and the public media attribute, with uncertain evidence, a significant part of the resistance problem in human medicine to the agricultural use of antimicrobials.

There is considerable concern that the subtherapeutic use of antimicrobials in food-producing animals causes the emergence of antimicrobial resistant bacteria (*Salmonella* spp., *Campylobacter* spp.), which may be transferred to humans who may develop clinical disease. Again, this may be difficult to treat because of antimicrobial resistance of the pathogens.

The 1969 Swann Committee Report in the United Kingdom, in response to concerns about an increased incidence of antimicrobial resistance in human and veterinary medicine, recommended that antimicrobials used in human medicine not be permitted for use as feed additives in food producing animals without a veterinary prescription. The banning of certain antimicrobials as feed additives did not cause a decline in the incidence of antimicrobial resistant bacteria in human and veterinary medicine.

From 1969 to 2000, several major expert committees examined the evidence that the subtherapeutic use of antimicrobials in the feed of food animals contributes to antimicrobial resistance in human medicine. All of the committees concluded that there is insufficient evidence to demonstrate a direct link between the use of antimicrobials in food animals and antimicrobial resistance in human medicine.

It has been difficult to trace the postulated steps from the use of the antimicrobial in the feed of animals to the emergence and transfer of antimicrobial-resistant bacteria to humans in whom it may cause disease. Those who argue that the use of antimicrobials in agriculture contributes to antimicrobial resistance in human medicine are unable to quantify the relative contributions to resistance made by their use in human and veterinary medicine. Several disease investigations in the 1980s claimed to have shown the link between the use of antimicrobials in farm animals and the isolation of antimicrobial-resistant bacteria from humans affected with salmonellosis. However, a review of the literature concluded that the evidence was incomplete for showing a direct link (Radostits, 1999).

Antimicrobial resistance is a major problem in human medicine, particularly nosocomial (hospital-acquired) bacterial infections in which the incidence of resistance has increased most dramatically because of the intensive use of drugs. There is general agreement in the medical profession that a major cause of antimicrobial resistance in human medicine is the overprescription of antimicrobials. Patients commonly expect physicians to prescribe antimicrobials for a wide variety of common infections for which antimicrobials are unnecessary. The failure of many human patients to comply with the prescription recommendations by not taking the complete course of the antimicrobials also contributes to the resistance problem. The incidence of antimicrobial resistance of several human pathogens has increased and continues to increase. Some multiple-drug-resistant strains of bacteria emerge in different parts of the world, persist for several years, and then disappear.

The people at greatest risk of developing clinical disease because of antimicrobial-resistant bacteria of animal origin are those already taking oral antimicrobial medication for a previous illness, immunocompromised patients, the young, and the elderly. Increased antimicrobial resistance is a problem in several pathogens that are not zoonotic; thus the resistance is unlikely associated with the use of antimicrobials in food animals but rather intensive and extensive use in human medicine. The most common and significant cause of disturbances in the normal intestinal microflora of humans is the administration of antimicrobials orally. Bacterial overgrowth and the emergence of resistant bacteria occur, which may lead to serious infections.

The use of antimicrobials deemed valuable in human medicine has been banned as growth promotants for livestock

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in some countries. However, banning their use in the United Kingdom in 1969 did not cause a decrease in the incidence of antimicrobial-resistant bacteria. In 1986, Sweden and Denmark banned the use of antibiotics as feed additives. In 1999 the European Community banned four antibiotic feed additives (virginiamycin, tylosin, zinc bacitracin, and spiramycin) as a precautionary public health measure.

Foodborne Illness

It is important to consider the circumstances of foodborne illness in humans in the context of any discussion of antimicrobial-resistant bacteria being transferred from animals to man. Meat and meat products are not bacteria free, and most foodborne illnesses are due to the improper handling of food and inadequate cooking. Moreover these bacteria may be pathogenic for humans whether or not they are resistant to antimicrobials. Thus the proper handling and cooking of food for human consumption must be given high priority.

The major foodborne pathogens are *Salmonella* spp., *Campylobacter jejuni*, and *E. coli* 0157:H7. Worldwide concern exists about the emergence of antimicrobial-resistant bacteria in the production of poultry, swine, and beef cattle production. However, the proportion of cases of foodborne illness resulting from antimicrobial-resistant bacteria is unknown. Foodborne illness in humans caused by the animal enteric pathogens is usually the result of the improper handling or inadequate cooking of ground beef and poultry. More than 90% of such human patients with foodborne gastroenteritis experience an episode of diarrhea and recover without the need for antimicrobials. The surfaces of beef cattle carcasses are contaminated with enteric bacteria immediately after removal of the hide during processing following slaughter. Fresh ground beef contains variable numbers of *E. coli* 0157:H7, some strains of which are highly pathogenic (*E. coli* 0157:H7), and rarely may be contaminated with *Salmonella* spp. Poultry is commonly contaminated with *Campylobacter* or *Salmonella*.

Little information is available on the prevalence of antimicrobial-resistant bacteria on the surface of beef carcasses. Major progress has been made in the last decade in the processing of beef carcasses after slaughter to reduce the microbial contamination of beef using the HACCP system.

Adequate cooking of meat such as hamburger eliminates all potential risks from bacterial contamination. Inadequately cooked beef hamburger is a major risk factor for infection with *E. coli* 0157:H7.

The Use of Drugs in Food Animals: Benefits and Risks

In response to growing public concern over food safety in relation to the use of drugs in food animals, the USDA and the Center for Veterinary Medicine of the FDA asked the NRC to form a committee to examine and review the benefits and risks associated with drug use in the food-animal industry (National Research Council, 1999). The NRC assigned the task to the Board on Agriculture, and the Committee on Drug Use in Food Animals was convened. The committee was charged with reviewing, evaluating, and making recommendations related to the need for drugs and their availability and accountability in agriculture, the benefits and risks to human health and food safety associated with food animal drugs, the development of food animal drugs and the process of approval of their use, and the emerging trends in animal health care and the availability of alternative management practices for raising food animals. In particular, the sponsors stressed the importance of evaluating the class of drugs known as antimicrobials.

The committee concluded that the use of drugs in the food animal production industry is not without some problems and concerns, but it does not appear to constitute an immediate public health concern; additional data might alter this conclusion. The greatest concern is associated with the use of antimicrobials in food animals in such a way that there is a potential for antibiotic resistance to develop in or be transferred to pathogens that can cause disease in humans. The report acknowledged that there may be a link among the use of antimicrobials in food animals, the development of bacterial resistance to these drugs, and human disease—although the incidence of such disease is low. A direct link among the animals fed antimicrobials, the emergence of antimicrobial-resistant pathogens, and their transfer to humans where they have caused clinical disease, which is difficult to treat with antimicrobials, has not yet been demonstrated clearly.

A substantial change in the human health risk posed by antibiotic use would affect not only how animal drugs are reviewed, approved, and used, but also how food animals are produced. It should be noted that antimicrobials are still effective for their intended purposes at the recommended dosages.

Bacterial resistance to antimicrobials will be the most important motivating factor in the development of new drugs to fight infections and in the modification of processes by which drugs are approved. Regulatory agency approval practices have improved in recent years and continue to do so. Reasonable balance in accountability, oversight, and veterinarians' access to alternative drugs has increased with the passage of the Animal Drug Availability Act (ADAA) and the Animal Medicinal Drug Use Clarification Act (AMDUCA) (Rhoda and Smith, 1999). However, those are only temporary solutions to a continuing problem.

Unless new antimicrobials become available, even the extra-label use of antimicrobials is expected to become ineffective. There is a great need to understand more clearly both the magnitude of the risk and the options available to minimize the risk while maintaining the benefits these drugs confer on agriculture. Constant vigilance in monitoring trends in antibiotic resistance in farm animals and humans is strongly encouraged.

New antibiotic drugs are needed to combat emerging animal diseases that do not respond to traditional drugs and thus threaten public confidence in animal agriculture and human medicine. Professionals in human health care should be concerned that they do not have enough specialty antimicrobials to treat resistant and emerging infections in humans, as should veterinarians. The question is, should newly discovered medications be held in reserve for human or animal use only? Antimicrobials should be available to treat specific human and animal diseases with proper accountability and oversight of the drugs used. Information gaps hinder the decision- and policy-making processes for regulatory approval and antibiotic use in food animals. A data-driven scientific consensus on the human health risk posed by antibiotic use in food animals is lacking.

The National Antimicrobial Resistance Monitoring System (NAMRS), which prospectively monitors changes in antimicrobial susceptibilities of zoonotic pathogens from human and animal clinical specimens, healthy farm animals, and carcasses of food-producing animals at slaughter plants, is in effect (Marano et al, 2000). The antimicrobial susceptibilities of indicator and zoonotic bacteria should be correlated with the use of antimicrobials used in the sampled herds.

There is a need for well-designed field trials to evaluate

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the effects of subtherapeutic antimicrobials in the feed of feedlot cattle on the susceptibility of enteric pathogens over the length of the feeding period. Control animals not being fed antimicrobials are also necessary. The antimicrobial susceptibility of the bacterial flora of the beef carcasses would also be determined at the time of slaughter and processing to determine the flow of the bacteria. It is important to examine the relationship between the use of antimicrobials and the emergence of resistant enteric bacteria and their dissemination at slaughter of the cattle and processing of the carcasses.

There is a need for risk communication between the scientists and the public to improve the understanding of antimicrobial resistance in food animals and how to reduce the risks of foodborne illness associated with the improper handling and inadequate cooking of red meat and poultry. Every effort should be made to explore risk reduction rather than risk elimination, which is not possible.

Based on the available information it is not possible to conclude with a strong argument that the subtherapeutic use of antimicrobials in the feed of feedlot cattle contributes significantly to antimicrobial resistance in human medicine. It is also possible that the probability of a cause-and-effect relationship is extremely low because of the complex nature of the events that must occur (Radostits, 1999). However, recent publications of expert committees from England (Advisory Committee on the Microbiological Safety of Food [ACMSF], 1999) and Australia (Joint Expert Advisory Committee on Antibiotic Resistance [JETACAR], 1999) concluded that the use of antimicrobials in food animal production leads to the selection of resistant bacteria that may be transferred to humans in food and cause human infections, which are difficult to treat. Human patients, physicians, veterinarians, drug companies, regulatory agencies, and food animal producers will have to address the issue. This will include the prudent use of antibiotics in human and veterinary medicine, improvement of food animal production practices, consideration of less dependence on the subtherapeutic use antimicrobials for the control of infectious disease, and the banning of the use of antimicrobials for growth promotion. The monitoring of antimicrobial resistance of animal and human pathogens will also need to be expanded.

Environmental Management

In geographic areas where animals are housed indoors or kept confined outside, management of the environment is a major determinant of health or disease. Much is now known about how environmental variables affect productivity of domestic animals. These include the following: (1) the adequacy of the ventilation of housed animals, (2) the daily fluctuations in temperature and relative humidity inside barns, (3) the quality of the air and the concentration of gases such as ammonia, hydrogen sulfide, carbon dioxide, and methane, (4) the comfort of stalls and pens, (5) the quality of the floor surface, (6) the manure disposal system, and (7) the population density of the animals.

The examples just listed are common ones, and there are many others. The methods of feeding and the amount of dust created by feeding systems may also have an important influence on respiratory disease. The method of cleaning and disinfection used in critical areas, such as the milking parlor and the milk house, and the quality of the bedding and ground surfaces where cows spend most of their time are important factors that can contribute to outbreaks of environmental mastitis in dairy cattle. The monitoring of these variables and how they affect productivity or contribute to disease is now a significant part of some health management programs. In the swine industry, pigs are raised indoors from birth to market, and ventilation, air quality, and the comfort of individual stalls for sows and the safety of farrowing crates for piglets are major considerations in swine health management programs. Housing quality and ventilation are considered to be important determinants of respiratory disease in growing and finishing pigs. Lameness caused by diseases of the feet is a major problem associated with floor quality and ground surfaces in dairy cattle confined indoors or in zero grazing systems. Enzootic pneumonia of housed dairy calves is closely related to the quality of housing and ventilation.

Clinical Research

Veterinary practitioners can serve an important role in the availability of new animal drugs by contracting as clinical investigators. Veterinarians who supply health management services to large herds have a particular advantage because of the existence of good record-keeping systems in such herds, and in most cases the owners are interested in the development of new drugs and vaccines. The provision of a health management service to livestock producers provides the veterinarian with an opportunity to do field research on food-producing animal farms. Because certain methods used for the treatment and control of diseases may not be applicable or economical on every farm, clinical research may be necessary on certain farms. Clinical field trials may be necessary to determine, for example, whether the diet of a certain herd should be supplemented with a nutrient such as copper or selenium to improve the growth rate of pastured sheep or cattle. A trial may be indicated to determine whether a vaccine is effective and economical in a feedlot situation or a beef breeding herd. Drug and vaccine manufacturers also need to conduct field trials on commercial farms under naturally occurring conditions, which provide an opportunity for the veterinarian to participate in the trial as a paid consultant. Clinical field trials must be well planned and designed scientifically so that the results can be analyzed statistically. This requires some knowledge of clinical epidemiology and statistics, and veterinarians planning to conduct field trials should collaborate with a veterinary researcher who can provide such assistance. The critical features of veterinary field trials have been described (Elbers and Schukken, 1995). A large potential exists for the use of randomized clinical trials in veterinary clinical research, especially in large herds (Lund et al, 1994). The basic features of the drug approval process in the United States and the important points for consideration when becoming a clinical investigator are available (Prater et al, 1996).

Animal Health Technicians in Health Management

Certified animal health technicians who are graduates of accredited training programs are a valuable resource as assistants in a large animal practice. They are able to do many of the routine elective procedures, such as dehorning, castration, and foot trimming, if these are part of the health management program of certain farms. In large animal practices that have clinical facilities for the intensive therapy of valuable animals, technicians are invaluable for the provision of intensive care, including intravenous fluid therapy. They can collect laboratory specimens, such as blood, milk, feed, soil, and water samples, which may be necessary as part of a control program or field study. They can assist with necropsies and the preparation of tissue samples for laboratory sub-

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mission. Technicians are excellent for the collection and preparation of animal health and production data for simple analysis or entry into the computer, if required. They can learn the use of some of the more commonly used computerized statistical programs for the analysis of data derived from field trials. Some technicians have been involved in information retrieval (of literature from the library), which is a valuable asset for the busy veterinarian. For large herds, regardless of the species, technicians can be collecting data and doing several different routine activities while the veterinarian is involved with veterinary diagnostic work. Technicians can be taught how to evaluate milking machine function to detect problems associated with mastitis. Large herds and feedlots have employed technicians to detect and treat sick animals according to a treatment protocol prescribed by the veterinarian. Technicians employed by a veterinarian and engaged in certain veterinary diagnostic and surgical techniques require veterinary supervision, as described in most veterinary acts. The training of personnel and monitoring of their performance is now becoming a major activity in dairy herds, and veterinarians will be required to provide the health and production protocols necessary to achieve optimum health and production.

COSTS AND BENEFITS OF A HERD HEALTH PROGRAM

Costs of Animal Health and Production Management

Health management veterinary services have many inherent costs. These include professional services on the farm; travel; drugs, vaccines, and other animal health supplies; the professional time required for the analysis of data and the preparation of reports to be sent to the producer; and telephone charges. There is little documented information on the total input costs of all veterinary services and supplies for the health management of herds of food-producing animal herds.

Traditionally, veterinarians have used one of three methods to charge for professional health management services. The most commonly used method is to charge for each professional hour the veterinarian is engaged in health management activities on the farm and in the office analyzing data and preparing reports. This is generally done for dairy and beef cattle herds, swine herds, and beef feedlots. A differential fee system may be used in which a higher fee is charged for skilled diagnostic work on the farm and a lesser amount charged per hour for analytic work done in the office. A second method is to charge a certain amount per head per unit of time (day, week, month, or year). In dairy herds, for example, the charge could be based on the number of lactating cows in the herd each month. In either system the veterinarian should outline in a written document the nature of the health and production management services that are to be provided, including the frequency of farm visits and the reports that are to be prepared for the producer. The time required for the preparation of reports is charged on an hourly basis, and an itemized account indicating all of the charges, along with the monthly herd health report, is sent to the producer. The costs of travel to and from the farm, telephone calls, and animal health supplies such as drugs and vaccines are additional. Animal health supplies may be provided by the veterinarian at a reduced gross profit by mutual arrangement with the producer. This may ensure that the producer uses the products that are prescribed by the veterinarian.

A contract method is used by some veterinarians and may be preferred by some producers. In this situation, the veterinarian agrees to provide a specified animal health and production service for a set professional fee per month or per year, which may include the provision of all services. The charges are usually determined on a per head basis and the contract can be renegotiated each year. Some contracts include a base professional fee plus a percentage of the increased profits made during the year. This provides an incentive to the veterinarian to promote high standards of health and production.

Veterinarians must understand that if they charge for advice, a written report must be provided to the client. The report is an extremely important document. Credibility is added when published articles supporting the recommendations are included in the report. Producers know that time was spent preparing the report and they are more likely to implement the recommendations. *Producers are reluctant to pay for something stated but are willing to pay for something written and documented* (Toombs, 1996). Veterinarians can use enterprise analysis to determine the value of their recommendations, thus allowing them to charge more appropriately for the services provided (Toombs et al, 1993).

A 1986 national survey of livestock producers in the United States obtained information on expenditures on veterinary services and animal health supplies (Wise, 1988a). Approximately 71% of beef producers used a veterinarian and spent an average of $315 (U.S.) per farm per year. Almost all dairy producers employed the services of a veterinarian or purchased animal health supplies from a veterinarian at an average of $1090 (U.S.) per farm per year. Only 59% of swine producers used a veterinarian for services or products, with an annual expenditure of $524 (U.S.) per farm. Approximately 78% of sheep producers used a veterinarian, with an average annual expenditure of $310 (U.S.) (Wise, 1988a). In general, owners of large livestock farms and ranches spent proportionately more on animal health products and less on animal health services than owners of smaller farms. Owners of large farms also spent proportionately less on veterinary services than did owners of smaller livestock farms. The relative amounts spent on the diagnosis and treatment of sick animals compared with the total amount spent on planned herd health programs were not determined.

The same survey sought information from food animal practitioners on the revenues from veterinary services and animal health supplies (Wise, 1988a). Approximately 62% of the average income of veterinarians was derived from professional services and 38% from sales of animal health supplies. Approximately 45% of professional service revenue was from sick animal services, 45% from well animal services, and 10% from consultative services. Income from consultative services including herd health programs, nutrition, and production analysis ranged from 5% to 7% for sheep and beef practitioners, respectively, to 11% to 24% for dairy and swine practitioners, respectively.

The amount of money spent on animal health services and supplies as a part of the total costs of production is low compared with other costs (Howe, 1988). Data from farm accounts indicate that veterinary services and medicines never exceed 2% of total farm expenditure, which is a minor proportion of total costs incurred by producers. However, this low cost does not necessarily mean that veterinarians can justify their services on the basis of the relative cheapness of their contributions, especially when compared with the increased production and financial returns that result from disease prevention and control. From an economist's point of view, the costs and benefits of veterinary services must be considered in the context of all other costs of the farming operation to determine whether the expenditure on veterinary services provides the best economic return to the farm.

A study of the veterinary and nonveterinary costs of

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disease in 29 California dairy herds participating in the NAHMS project from 1988 to 1989 revealed that the cost of disease prevention accounted for 11% of the total costs of all health-related expenditures (Weigler et al, 1990). From 1987 to 1988, in 60 beef cow-calf herds in Tennessee, the cost of preventive veterinary services accounted for 8.8% of the total cost of preventive actions, which included drugs and vaccines (New, 1991). Most of the costs in both studies resulted from the purchase of drugs and supplies to treat and prevent disease, and only a small amount resulted from professional veterinary services.

The economics of the rural practitioner market has been examined using the neoclassical economic theory as a foundation (Radke and Lloyd, 1996). There is a widespread belief that rural veterinary practice is undesirable because of the hard work, long days, inadequate professional income per hour, and poor self-image. There is a demand for rural veterinary service to the livestock industry, but a declining number of new graduates are entering rural practice. It has been suggested that one solution is to change the admission requirements to increase the number of graduates with a meaningful farm animal experience who may have a greater dedication to the farm community. However, such a mechanism to provide a stable market equilibrium would increase the welfare of consumers at the cost of rural veterinarians.

Economic surveys have indicated that all veterinarians, perhaps with the exclusion of those charging the highest prices, are operating in the inelastic portion of the demand curve for veterinary services (Radke and Lloyd, 1996). Since price and quantity are inversely related, a fee increase would normally decrease quantity demanded. With inelastic demand, the supplier's revenues will increase with an increase in price. At least one economic survey suggests that demand for the profession as a whole was unaffected by an increase in fees (Radke and Lloyd, 1996). The majority of veterinarians feel that they are underpaid relative to other professionals with similar postsecondary education. Large animal practitioners could move in the direction of solving the problem of inadequate remuneration and excess demand with one action: raising professional fees.

Raising fees appears to solve a number of the problems facing rural practitioners. Increasing rates would increase income, decrease supply, and decrease the number of hours worked. If demand still required more suppliers (veterinarians), profit in the market would be sufficient to attract and maintain employees or competitor veterinarians. With sufficient financial returns, an increased number of talented young people with rural backgrounds, who in the past have forsaken a career in veterinary medicine, would be stimulated to apply to veterinary college, thus meeting the desires of employers.

Social and Economic Benefits of Animal Health and Production Management

Social Benefits

The benefits of animal health management programs accrue to society as a whole. Disease in farm livestock has always been a problem of considerable importance to producers. The production of wholesome human food from animals is a major objective of livestock industries. Producers employ the services of many different professionals, pharmaceutical and feed companies, and government agencies to assist in achieving this objective. Because some diseases of livestock are infectious and can spread from farm to farm, and because zoonoses can adversely affect the human population, society also benefits from effective animal health management programs. Disease control programs benefit society by improving the quality and hygiene of food, public health, maintenance of trade in livestock, and increased awareness of welfare of animals.

Economic Benefits

The economic benefits derived from a herd health program have been the subject of considerable debate. When progress has been made and performance improved, it is difficult to identify which factor (or combination of factors) is responsible. A successful, comprehensive herd health program involves a combination of more effective management by the farm staff, the accurate recording of data, the use of new information, the introduction of specific disease prevention techniques, regular visits by the veterinarian, improved nutrition and housing, improved breeding programs, and other intangibles that are difficult to identify.

Four methods used to calculate the financial impact of veterinary services in beef cow-calf herds have been described: analysis of value of therapy; partial budgeting, standardized performance analysis-financial (SPA-F), and spreadsheet analysis (Toombs, 1996). The SPA is a major asset to cow-calf practitioners in the United States and is described in Chapter 13.

Enhancement of the profitability of the producer must be a primary objective of health management programs. The increased interest in applying economic principles to the analysis of veterinary services is an important step toward meeting this objective. Farm-level analysis of animal health economics is now being incorporated with animal health management. This involves selection of the appropriate analytic techniques and the use of economic parameters that adequately represent the actual situation on the farm. An important aspect of economic analysis is that management advice must be based on information that assesses the risk of loss from disease and the effect of animal health management practices. Without such information, it is difficult to assess the economic benefits of animal health management relative to other aspects of the farm.

The veterinary costs of a herd health program are part of the variable or optional costs of farming, such as those associated with feed, fertilizer, supplies, and services. Based on cost-benefit analysis techniques, the net return to the producer of money spent on veterinary services directed toward a comprehensive herd health program has been calculated for some specific disease control techniques, such as control of mastitis and improved reproductive performance in dairy herds. The net returns have been on the order of 200% to 500%.

Some indication exists that, as the level of performance improves, health costs decrease. Health costs are lowest in dairy herds with near-annual calving intervals compared with much higher costs in herds with longer lactation periods.

Agricultural economists contend that the economic analysis of disease control has been focused on an important but nevertheless narrow subset of economic problems (Howe, 1988). The economic analysis of disease control has centered on cost-benefit analysis, which is a form of simple accounting ratios. Economists are concerned more with the real resources (inputs) and real products (outputs) that underlie financial expenditures and receipts than with the money values themselves. Examples of real resources are veterinary manpower and animal health supplies, farm labor, buildings, machinery, land, breeding livestock, and feedstuffs. Examples of real products are milk, meat, eggs, and wool (Howe, 1988).

Economics is the study of the allocation and the use of scarce resources in production. This means that it may be more economically beneficial for producers to spend money

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on other aspects of the farming operation rather than on veterinary services. Thus the term "opportunity cost" is central to the appraisal of economic efficiency. The opportunity cost of using resources for one purpose is the return foregone by not using those resources elsewhere (Howe, 1988). If the potential alternative return is greater than that obtained from retaining resources in their present use, the resources should be reallocated. The effect of the reallocation is to benefit society. Economists may thus claim that the fact that expenditures on veterinary resources are more than covered by the consequent returns from healthier livestock may be good for farmers, but not for society as a whole. It all depends on whether there are higher returns to be earned from transferring those resource expenditures to other uses. It might be suggested that there is no good reason for animal disease to be controlled at all costs. This suggests that it may be necessary to define the economic optimum level of disease in a livestock population. From the producers' point of view, it would be that level of disease that is consistent with their welfare being maximized when each has allocated resources in the best possible way among all competing uses, such as disease control, crop production, bank investments, and building and equipment purchases.

From an economist's viewpoint, cost-benefit analyses have limitations in the economic analysis of animal health management. The analysis is useful for evaluating an investment when the returns, the investments, or both are spread over time. However, it does not indicate whether the investment being appraised was a sensible choice in the first place (Howe, 1988). When the veterinarian and the producer consider various options for the control of a specific disease, they are making choices. In a broader context, however, economics is also equipped to help identify a preferred option from all the possibilities for resource use. A comprehensive economic appraisal to support a policy decision should at least consider the consequences if other diseases remain uncontrolled as a result, or if resources for the control of other diseases are reduced. Thus the opportunity costs from allowing one course of action rather than another (e.g., vaccinate the animals or buy a new high-pressure sprayer for cleaning) must be taken into account. Cost-benefit analysis usually begins from the position that an objective, such as controlling a given disease, has already been determined, but it is important to be aware that the decision about whether the objective is worthwhile at all when compared with the alternatives has been preempted. In other words it is not a means for identifying the optimum or most efficient course of action.

The veterinarian must consider that there are circumstances in which disease can be controlled without the use of veterinary resources. Whenever disease can be controlled by more than one method, rational producers are expected to aim for the cheapest combination of methods possible for any given level of output. At one end of the scale, dependence on veterinary input is effective in keeping the incidence of disease at low levels. At the other end, the use of veterinary services can be minimized by adoption of the principles of disease control and by using all available resources more effectively. Between the two extremes, it may be possible to manage health and production by various combinations of veterinary and nonveterinary resources. That level should be the lowest cost combination of resources that should be sought; this is difficult if not impossible to identify by cost-benefit analysis.

Veterinary medical economics are presented in Chapter 2.

Aids to Management

An established operative herd health program with a reliable records system automatically leads to the development of several useful aids to management. In other words the program helps the producer organize the management of health and production. These management aids have been most successful in dairy and swine herds. One example is the development of action lists, which assist the producer in identifying when certain events occur or in determining which actions must be taken with particular animals. These animals are highlighted by the records system, which prompts the producer to perform the action when necessary. Some examples in a dairy herd include the identification of cows for reproductive tract examination (pregnancy diagnosis, postpartum examination, or infertility); the use of prostaglandins in postpartum dairy cows; cows to be dried off; cows due to calve; cows to be culled; an improved heat detection system using heat detection aids; cows for mastitis examination and the regular use of diagnostic tests, such as the California mastitis test; and cows to be examined because of a history of clinical disease.

Other aids to management include predictions of calving pattern, regular assessment of nutritional status of the animals and feed requirements, automatic milking parlor data recording systems, and cash flow. There are similar examples of aids to management in swine herds, beef feedlots, beef cow-calf herds, and sheep flocks. The central theme is that a health management program involves a system that alerts the producer automatically to pay more attention to the various points in the production cycle at which certain procedures need to be performed and when.

Continuous Assessment of the Farming Unit

The herd health program can be regarded as a recurring assessment of the farming unit as a functioning unit. The assessment can be used at any time as a check on the efficiency of a manager, herdsman, or business partner. The manager or managing partner can also use the assessment as justification for a change in shares in the proceeds. For a banker, investor, buyer, or seller, an annual report can provide evidence of biological and managerial efficiency to supplement a financial statement of profit and loss. In extension exercises, field days, producers' discussion groups, and meetings, the information provided in annual and monthly reports is most valuable because of the accuracy and local origin of the data.

Efficient Use of Rural Veterinary Practitioners

Rural veterinary practices have participated in governmental disease regulatory work on a fee-for-service basis for many years. The government benefited by being able to extend its surveillance and eradication programs. By using practitioners as part-time and casual employees, the government was able to remain flexible and relatively uncommitted for a significant segment of its work. Veterinary practices benefited by an improvement in their financial viability, partly because of added income but largely because the regulatory work could be programmed during parts of the year when emergency work was at a low level and practitioners tended to be underemployed. Eradication programs for brucellosis and tuberculosis provided most of this regulatory work for veterinarians. The success of these programs has brought about a marked reduction in the volume of this work available to practitioners and in the regular income that it used to provide. In veterinary practices in which work is seasonally distributed, such as beef cow-calf practice with the peak at the time of calving, herd health programs are a suitable alternative to governmental regulatory work. The reproductive program on which they are based is busiest in the slow season for emergency work.

Progressive and successful producers are able to integrate

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the information and advice that they receive from various sources and to make the appropriate decisions themselves. However, many other producers do not have this capability. Thus an opportunity was created for veterinarians to provide producers with a list of health management options, rank the alternatives, and recommend the best solution after making an objective evaluation of the herd using all the information available.

Veterinarians are situated in the advisory support system of livestock producers so that they are the most strategically placed to ensure that integration exists among the components of management.

FACTORS AFFECTING DEVELOPMENT OF HERD HEALTH PROGRAMS

Several factors have slowed progress toward the widespread adoption of effective health and production management techniques by producers and have retarded the delivery and marketing of those techniques by veterinarians to producers. Many producers are familiar with the economic consequences of clinical disease in animals but do not fully appreciate the existence of subclinical disease. Often they do not recognize that subclinical disease can impair productivity and, on a herd basis, can be a greater source of economic loss than clinical disease. They are also not fully aware of the economic returns that are possible by monitoring animal health and production accurately on a herd basis and by taking positive action to improve performance of the herd. Traditionally, producers were willing to pay for emergency veterinary services on individual, clinically ill animals. However, many producers and farm managers are still reluctant to pay for veterinary advice on health management and production when the results are not immediately obvious. Interviews with large-scale dairy farm operators have indicated that they perceive veterinarians only as primary providers of clinical services. Large dairy farms require an integrated approach to herd management, but the operators have not consulted historically with veterinarians for such comprehensive production-oriented management advice. Instead, they have employed the services of agribusiness industry representatives, including graduate agronomists, animal nutritionists, agricultural engineers, accountants, and other professional agrologists for advice on management and production, with emphasis on economics and how to reduce the costs of production.

Competence of Veterinarians

It has been suggested that there is a shortage of food animal practitioners who can provide profitable veterinary services to primary livestock producers. It is thought that this shortage may continue because of the shortage of adequately prepared graduates. "Food animal veterinary practice serves food animal producers and consumers and must respond to the forces that influence the clientele it serves" (Leman, 1988). Food animal practitioners need to be more knowledgeable in the areas of health, information, and farm management and must be effective communicators and good problem solvers. If they do not have these skills, herd health programs cannot be developed.

Veterinarians generally have few conflicts, with no vested interest, when giving advice about nutrition, proper facility design, and other general management issues. Thus this perception of the veterinarian as a clinician only deprives the dairy operator of an objective, integrated appraisal of herd health, management, and production. Changing this perception requires a restructuring of the curricula of many veterinary medical schools. The emphasis needs to be on courses in clinical epidemiology, health management on a herd basis, nutrition, and veterinary economics (Pritchard, 1989b). The general college education of the veterinary student should first provide a broad understanding of people, the natural and social sciences and the humanities, personal skills in communication, and the opportunity to pursue scholarly activities in areas of special interest. The professional veterinary curriculum should enable students to acquire the core of biomedical and veterinary knowledge, skills, values, behaviors, and attitudes that are essential to all veterinarians. In addition, entry-level clinical skills with at least one class of animals or species are of utmost importance. The veterinary curriculum should include equal emphasis on health and disease and on individual and population approaches to disease prevention and control; they should provide clinical experience in the care, husbandry, and management of the various animal species, as well as the management of disease (Pritchard, 1989b). Teaching strategies and methods should emphasize the development of the ability to find and use information rather than the accumulation of information as the primary objective of the professional curriculum. High priority should be placed on the acquisition of skills, behaviors, and attitudes that can motivate graduates to continue to learn and develop their competence throughout their professional lives (Leman, 1988).

The perception by the producer that veterinarians are not production oriented has been one of the constraints of more widespread employment of veterinarians as health management advisors. Much of the gain in preventive veterinary medicine in the recent past has occurred because of a change in the attitude of farmers toward a more financially conscious appraisal of their activities than they applied previously. Some of the change has been the result of better education generally, but primarily it has been an appreciation of the need to maintain a sufficient margin between costs and income in order to enhance their standard of living or simply to service their large financial commitments. Cost-effectiveness and benefit-cost analysis have become the important yardsticks, rather than winning at cattle fairs and shows or topping the prices at fat stock shows or wool sales. When this attitude about economic viability is applied to health and productivity, there is a tendency for technical services and advice to be used more to the mutual advantage of the service and the farmer. The trend toward the greater use of advisory services has been followed by a generally significant improvement in the standards of animal management and farming. This trend has been assisted by the disappearance of many inefficient farms, brought about by the cost-efficiency squeeze. In some areas the surviving farms absorb the others, and farm sizes have increased. In general, the larger the farm, the more demand there is for advice on the prevention of loss and for the development of planned health management programs.

Goals and Values of Producers

The goals and values of producers have been responsible for some of the slow growth of herd health. An analysis of the goals and values of a cross section of British farmers revealed that the smaller farmers place more stress on intrinsic aspects of work, particularly independence. Farmers with larger businesses, however, are more economically motivated and are more likely to seek and consider consultants' advice about health and production management.

The personal characteristics and attitudes of producers also influence livestock performance (Tarabla and Dodd, 1990). Favorable attitudes toward credit and risk, those who actively seek new information, good household structure, and high level of participation in voluntary farm organiza-

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tions have all been reported to influence farm performance positively (Tarabla and Dodd, 1990). In dairy herds a positive attitude toward milking was inversely related to SCCs and positively associated with milk production. This suggests that a positive attitude toward the correct application of management procedures is beneficial. A producer who is aware of and can understand subclinical mastitis is more likely to implement control measures that can influence herd cell counts and butterfat production. Educational efforts have been effective in implementing mastitis control procedures in commercial dairy herds.

Livestock producers have a high degree of confidence in their own knowledge and ability. They have typically had a lifetime of practical experience in addition to a college degree in animal science or agriculture. Producers commonly consider themselves the single best all-around source of information for making decisions affecting their farm (Straw, 1997; Wise, 1988d). Straw (1997) said, "Veterinary practice encompasses the art of dealing with people, the science of medicine, and the politics of combining professional ethics with business necessities." Producers are not an "easy sell."

The producer's attitudes and management practices influence livestock performance (Bigras-Poulin et al, 1984a,b). Some producers comply with certain recommendations regarding disease control that seem to be ignored by others, yet others do not keep records or, if they do keep them, may not use them. Interactions among attitudes and management practices suggest that attitudes act as effect modifiers on the relationship of management practices to herd performance (Bigras-Poulin et al, 1984a,b). This suggests that attitudes should be measured and considered before proposing management practices to improve performance. The level of compliance is a major factor affecting the development and success of herd health programs.

Record-Keeping System

Another important factor affecting the rate of development and the success of herd health programs has been the lack of reliable health management records that can be analyzed regularly. The success of a herd health program depends on the competence and enthusiasm of the veterinarian, the management expertise of the producer, and the ability of the program to demonstrate progress through improved performance. Only the records can help to document improved, cost-effective performance. When reliable records are lacking or cannot be analyzed easily, the veterinarian cannot demonstrate to the producer that progress has been made. With no clear evidence of progress, the producer may become disinterested in the program.

Economic Value of Animals

The economic value of the animal can influence the development of herd health. As the value increases, the need to reduce the risk of loss of the individual or its productive capacity increases. As the value of food-producing animals continues to increase, the need for diagnosis and treatment of individual sick animals increases. At the other extreme, when the economic value of animals is low, such as beef cattle and wool sheep, the treatment of individual animals is given low priority. There is a tendency for animal husbandry and management to be considered more important than specific health maintenance programs. The emphasis is on nutrition and reproductive performance. Disease control strategies, such as those for internal parasites, blowfly infestation, and footrot, are developed for application to all farms in the area rather than adapted to suit the circumstances or resources of a particular farm. For these reasons, planned health management programs for wool sheep and, to a lesser extent, for range cattle tend to emphasize production, with less emphasis on disease control. The opposite is the case in dairy cattle herds, in which both the capital value and the potential worth of the productivity of individual animals are high. Thus maximum veterinary intervention is usually requested. The risk of disease losses and the need for veterinary supervision are even greater in the large, factory-type farming units that are common in most developed countries (Watson, 1980).

Emergency Individual Animal Medicine

Emergency veterinary medicine and the revenue from the sales of drugs and vaccines have accounted for a large part of the gross and net revenues in well-established rural veterinary practices. In part, these revenues have contributed to the slow growth of herd health in some areas. In a study of the U.S. market for food animal veterinary medical services, approximately 62% of the veterinarian's revenue was attributable to professional services and 38% to veterinary product sales (Wise, 1988a,b). As long as veterinarians are making a good living from emergency veterinary medicine and prescribing and dispensing animal health supplies, there is little incentive to develop herd health programs. The fact that emergency work is satisfying to some veterinarians and producers has further slowed progress.

Uncontrollable Factors

Health management programs may be affected by uncontrollable factors such as feed supplies, the market value of livestock, the prevalence of disease in the herd, and the diagnostic laboratory services available to the veterinarian. Large fluctuations in the supply of feed can cause major disruptions in performance. A marked decline in the market price of livestock can force farmers to invest scarce resources elsewhere on the farm. A sudden, unexpected epidemic of an infectious disease can cause large economic losses, and the farmer may lose confidence in the veterinarian's ability to control disease.

Successful Health Management Veterinary Service

Some veterinarians may lack the experience and confidence necessary to provide a comprehensive animal health service that includes investigations of the nutritional status of the herd, housing requirements, reproductive performance, and other production-oriented aspects of the herd. However, veterinarians who give high priority to herd health can quickly develop a reputation as herd health specialists who can provide an integrated, production-oriented, preventive veterinary service. A busy veterinary practice can also schedule herd health work during those periods of the year when there is insufficient emergency work to support the practice staff financially. In this way the work can be balanced throughout the year.

The following factors are important in the provision of a full health management program to a livestock producer (Esslemont, 1995):

- Develop an enthusiasm.
- Become an expert in the service being provided both in veterinary matters and in communication.
- Learn the operation of the computerized recording system on a few pilot herds.
- Use those herds with which the producer is fully cooperative.
- Establish and record the farm background, objectives, tar-

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gets, aspirations, farm staff, and limiting factors.
- Understand the financial constraints of the farm.
- Be aware of and know who else is advising the farmer.
- Determine the daily operation of the farm using a checklist of every production procedure on the farm.

THEME OF THIS BOOK

The theme of this book is that the most important objective of food-producing animal veterinary practice is the maintenance and improvement of the efficiency of livestock production by the management of animal health. This involves several different but related activities and responsibilities, including the following:

- Providing the most cost-efficient method of diagnosis and treatment of sick and injured animals and returning them to an economically productive status, or to a point at which slaughter for salvage is possible, in the shortest time possible.
- Monitoring animal health and production of the herd on a regular basis so that actual performance can be compared with targets of performance; then the reasons for shortfalls in production or increases in the incidence of disease can be identified as soon as possible, so that appropriate and cost-effective action can be taken.
- Recommending specific, preventive veterinary programs for diseases that are risks in a particular environment.
- Setting up planned health management programs for individual farms, with the objective of maintaining optimum productivity through animal health management.
- Advising on nutrition, breeding, and general management practices.
- Encouraging livestock producers to maintain standards of animal welfare that comply with the views of the community.
- Promoting management practices to ensure that meat and milk are free of biological and chemical agents that can cause disease in humans.

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CHAPTER 2

Quantitative Tools for Production-Oriented Veterinarians

BARRETT D. SLENNING

WHY BOTHER WITH THIS NUMBERS STUFF?

Most veterinarians enter the field because they enjoy working with animals and seem to do pretty well with the curriculum's emphasis on the basic sciences and the biological bent of physiology, anatomy, medicine, and related subjects. Had their main enjoyment been with mathematics, they would have become engineers, accountants, or statisticians. In fact, most practitioners dislike messing with numbers—balancing checkbooks, doing taxes, or putting together budgets—because it all seems so tedious, dry, and uninviting. For the most part that perspective is correct; mathematics does not have a lot of warm, fuzzy rewards to it. Of course, there is not a lot of excitement and joy in digging holes in the ground or cutting up pieces of wood, either. Yet dirt must be moved in order to garden, and wood must be cut in order to build a deck, so many people spend their weekends happily digging holes and cutting up wood. The same is true for number crunching; for production consultants, applied mathematics is a means to an end, not an end in and of itself. The numbers are worth bothering about if the end is a worthwhile one—and it certainly is.

The end most practitioners in production medicine attempt to achieve is the clients' better management of their animals in a consistently improving manner, so that they can reach their own goals of animal welfare, pride, profit, peer recognition, and financial stability. The old adage in business schools, "If you can't measure it, you can't manage it," applies to production medicine, for without some means of measuring health and productivity, there is no way to determine if the client's animals are benefitting. However, just knowing that clients' cows are producing more milk, or that their piglets are gaining more weight, is also not enough. A few decades ago practitioners could (or thought they could) justify their existence solely through biological arguments. They could run cultures and sensitivities to help a client decide which antimicrobial was the best for a certain bacterial pathogen. They could run serologies and help a client select the best set of vaccines to protect a herd. Those are biological arguments, pure and simple. But clients live not only in a biological world; their world has economic aspects and is not nearly as clean and certain as a set of *in vitro* lab results would suggest. Hence they need recommendations justified in more than strict biological terms. Practitioners must be prepared to answer some difficult questions:

- "Okay, Doc, this new vaccine seems to be better than the one I have been using. But is it better enough to be worth the extra costs of making a change?"
- "But what if the new processing program is only half as effective as you believe it will be, Doc?"
- "If I increase the amount of feed, I increase my costs, and my lender already says my costs are too high. How can I afford to make more money if I go broke in the process?"

To address such concerns, practitioners must become conversant with some quantitative tools. They need to understand how health and productivity can be measured and monitored and how to identify differences among groups of animals (epidemiology and statistics). They must be able to make sense of the uncertainty inherent in their information sources for making decisions and find ways to help clients put these factors together to make decisions about managing their farms (diagnostic test evaluation and decision theory). Practitioners need to have the skills to correlate significant health events and procedures with financial outcomes (economics). They must be able to dig through the literature to identify the nuggets of applicable and relevant information that exist (critical evaluation of the literature). Some of these topics are inherently quantitative, and others are only partly so. However, in total, they represent a set of analytical tools by which a production medicine veterinarian can influence the health of entire herds while attending to the financial well-being of the farms that own the herds.

This chapter introduces the aforementioned skills. "Epidemiological Considerations and Definitions" brings everybody up to speed with the jargon. "Statistics for Practitioners" looks at simple in-the-field techniques as well as more complex computer-based methods. "Diagnostic Test Evaluation" goes beyond merely reading test results to actually interpreting them. The "Economics" section presents some basic techniques in economics, from cost accounting through decision criteria. Much of this information comes together in the "Decision Therapy and Methods" section, in which I outline ways to help establish valid means of working through the uncertainties and outcome values derived from different courses of action. Finally, "Evaluating the Literature" briefly discusses issues of literature review, specifically where the literature is economic in nature.

EPIDEMIOLOGICAL CONSIDERATIONS AND DEFINITIONS

Overview

Epidemiology is the fundamental discipline involved with the study and measurement of health patterns over populations (Schwabe et al, 1977; Martin et al, 1987). Technically speaking, "epidemiology" is the study of health in humans. The branch that looks at health in animal populations is actually "epizootiology." Specific terms are used when focusing on birds ("epiornithology") and fish ("epiichthyology") (Martin et al, 1987), and terms exist for other species as well. For most of us, though, the only time these last three terms are of value is when we wish to be excruciatingly irritating to people at cocktail parties or seminars. Thus "epidemiology" is used in this chapter as the generic term for the study of health and disease over populations of any type of animal, human or otherwise.

Epidemiology is a process-oriented discipline. As with the earlier hole-digging analogy, epidemiology is a means to an end, not an end in and of itself. Being process oriented, it

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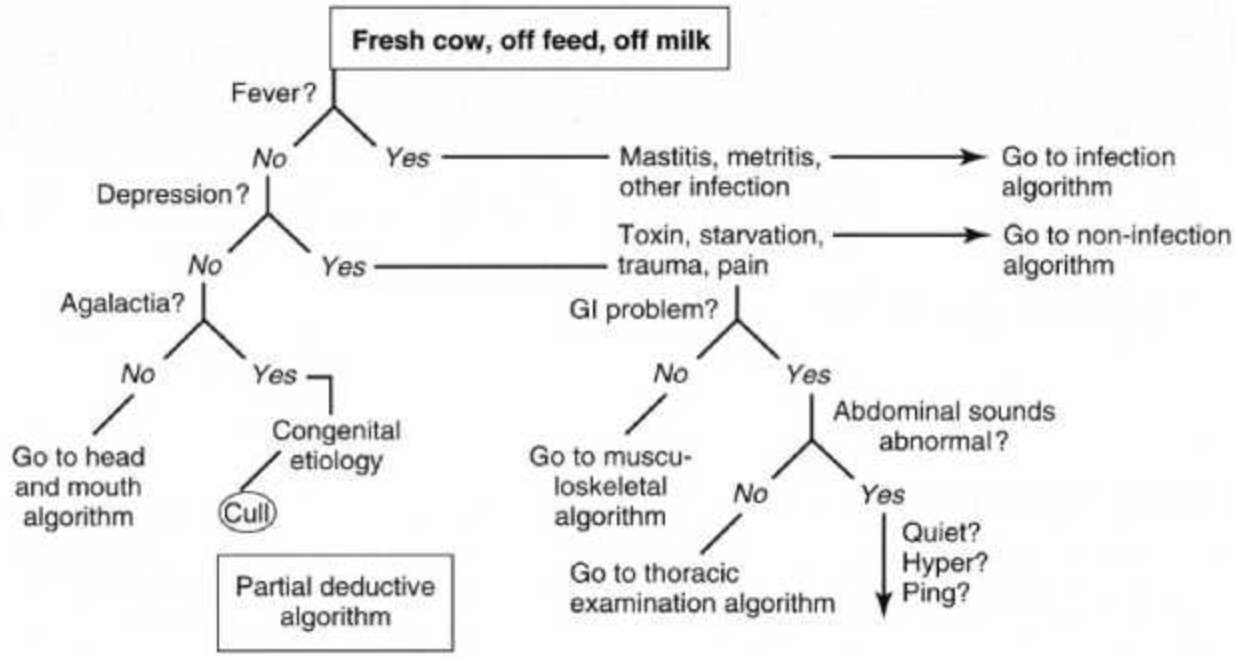

FIG. 2-1 Example of a diagnostic algorithm that could be used in a deductive process to diagnose a disease in an individual animal.

provides the practitioner with a conceptual "lens" through which to view the world and a formal set of tools by which some sense of that world can be made. The first lens-like aspect of epidemiology deals with how disease is approached differently when populations, as opposed to individuals, are discussed. This perspective affects what are seen as reasonable causes of ill thrift, what are determined to be possible avenues to ameliorate the problem, and the risk of failing to get back the costs of treatment. The second interpretive aspect of epidemiology can be considered in two parts: descriptive and analytical epidemiology. Descriptive epidemiology attempts to define the situations surrounding a disease event. Analytical epidemiology attempts to compare groups with and without disease. While they have different goals, they share many tools. The next section looks at how disease differs in the individual versus population perspective, and subsequent sections address the descriptive and analytical aspects of epidemiology.

Disease in Individuals Versus Groups

With a group perspective, the unit of interest becomes the group and not the individual. Because of this, it can become unclear in what is meant when a herd is or is not considered "infected" with a disease.

Infection can mean that at least one animal in the herd or group has evidence of the disease. This definition is usually reserved for diseases that are highly contagious to humans (brucellosis or tuberculosis) or other animals (equine infectious anemia), or for diseases that have, as their major impact, problems with import-export and animal movement. Examples of these are bluetongue and bovine leukosis in cattle, venereal diseases in nearly all species, and some respiratory virus infections for show animals. The lack of infection, or calling a herd "clean" in these situations, requires the demonstration of *no* evidence of disease in the herd.

In addition, infection can mean that the prevalence of the disease is above some threshold level. The threshold is often taken from a local or regional "expected level" or from an estimate of when a problem reaches economic significance. As an example of the latter, dairy herds with only occasional identifications of mastitis pathogens such as *Streptococcus agalactiae* are often considered "free" from an operational point of view. To be at such a low level, the herd is considered to be presumptively practicing good sanitation; risk of a blow-up is small. Chasing down the "last Strep cow" is not considered worth the time, effort, and money. A herd can be considered "negative" for these types of disease with evidence that the diseases do not exist, or at least exist below some established threshold level.

Disease Diagnosis in Individuals Versus Populations

Diagnosis in Individuals: Deductive

Diagnosis in individuals is deductive (i.e., goes from general signs to specific etiologies [causation]). When faced with an ill individual, the practitioner begins by making a list of "normal" comparisons (i.e., temperature, pulse, respiration, attitude). Each "abnormality" is a clue to the cause of the illness. Often a deductive process can be depicted as an algorithm, or series of questions. The answer to each question takes the examiner down an increasingly branching decision process as illustrated in Fig. 2-1.

In most cases the veterinarian can *deduce* the disease causation, or at least narrow it to a couple of choices, from the list of signs and symptoms. Hence, a cow as illustrated in Fig. 2-1, seen within the first few weeks of lactation and with poor appetite, gastrointestinal disturbances, poor attitude, and an audible "ping" in the left side of the abdomen, is very likely to have a left-side displaced abomasum.

Diagnosis in Herds or Groups: Inductive

Diagnosis in herds or groups is inductive (i.e., goes from specifics in a few individuals to generalities about the group). When a herd is performing at less-than-desired levels, the signs are rarely precise (Fig. 2-2). Again, in a dairy, the signs may be chronic milk loss and thin cows. All of the possible things causing those two signs could be listed, but the exercise would seem worthless after about 15 pages of data.

The four basics should be identified: who, what, when, and where. *Who* tells which animals are involved (young versus old, high producers versus low producers). *What* tells how the problem is signified (i.e., *what's* happening to *who*). Answering *when* the problem occurs (age, stage of production,

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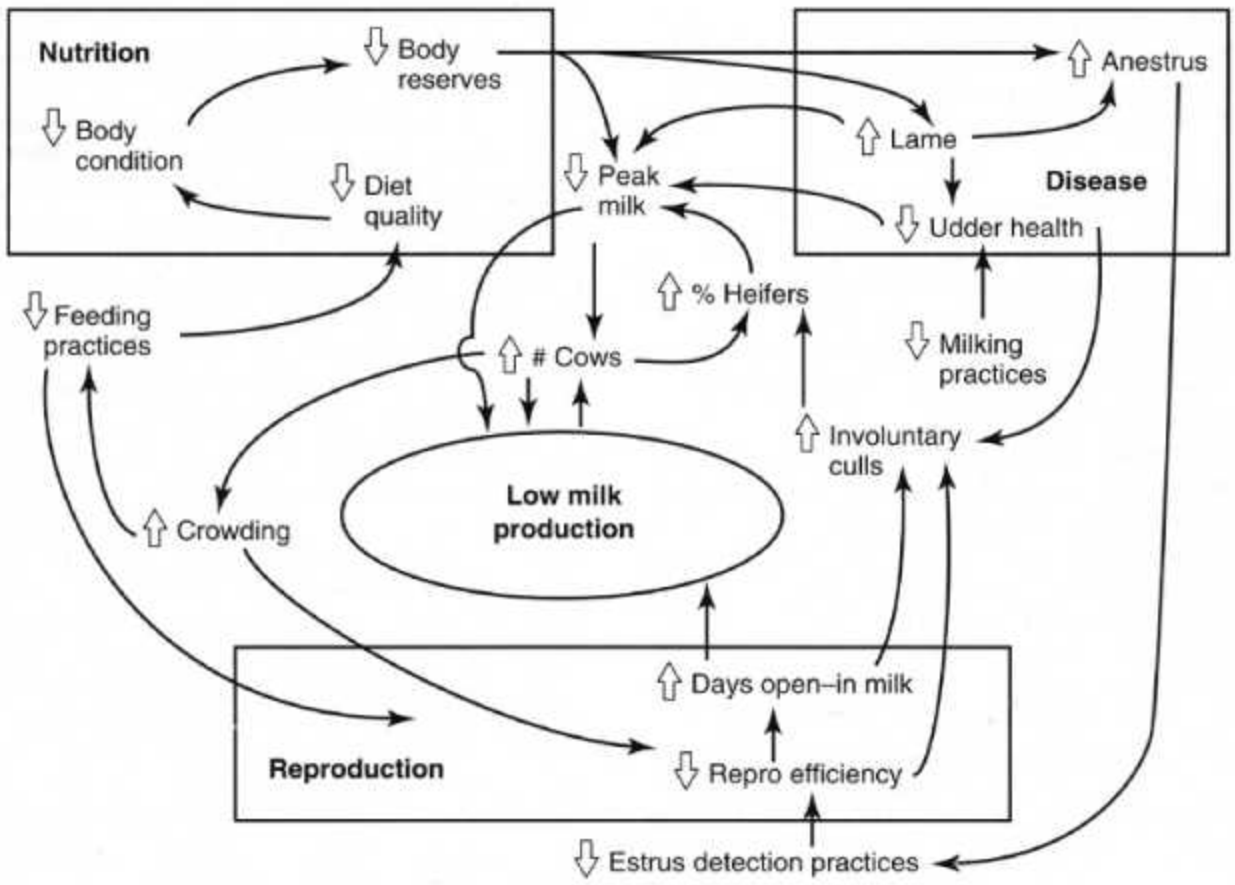

FIG. 2-2 Depiction of hypothetical low milk situation on a dairy farm with multiple factors affecting the problem in a network that is not amenable to a deductive algorithm for solution.

season, day of the week) helps to identify the dynamics of the process. *Where* the problem is most apt to occur (i.e., which pen, house, or farm) also offers clues into the type of transmission and etiology.

Is This "Individual Versus Population" Thing Going Anywhere?

Comparing disease definition and diagnosis for individuals versus populations leads to the realization that either model can color the perspective of what is happening and therefore what can be done. For instance, an exclusively individual animal focus would frame a question as, "What caused these cases to occur?" A population focus, however, might look at the same incident and ask, "What causes such a high number of cases in this herd?" On first reading, the difference might be considered purely semantic, but it is not. The individual perspective is looking for mechanisms, and therefore treatments, to affect high-risk individuals. The population perspective looks to shift the population's distribution of risk.

For example, in a situation in which a sheep flock was losing lambs to neonatal diarrheas, the individual perspective would focus on the sick lambs, find they had low plasma proteins, and interpret this as failure of passive transfer. Plasma transfusions or forced colostrum feedings might be instituted to decrease the likelihood of disease for high-risk lambings. The population focus, on the other hand, might concentrate on the lambing shed sanitation or prelambing ewe nutrition, attempting to improve hygiene and health for all the animals and thereby decreasing the incidence of disease across the flock. Of course, few people would actually look at a problem in only individual or population terms, but the example serves the point: How a problem is viewed influences how the tools that affect that problem are viewed.

This "individual versus population" perspective matters in terms of risk and level of reasonable investment. The individual focus places all the investment (time, effort, money, management) in the individual animal (i.e., only one animal benefits by a treatment); therefore the returns on that investment must be produced by that individual. If the required investment is greater than a reasonable expectation of what the animal could produce, the rational choice is to avoid making the investment. Further, placing all the responsibility for those returns on one individual also means that investment is lost if the individual is lost. The population focus, on the other hand, places the investment on the entire flock (i.e., each lamb born benefits from the treatment), so the needed return is carried by the whole flock (Galligan et al, 1993). Spreading the responsibility to more than one animal for paying back the investment reduces the risk that the debt will not be met.

Some segments of veterinary medicine are still almost exclusively in the individual-orientation camp (companion animal practice, for instance), whereas other segments have gone almost entirely to the population-orientation perspective (wildlife, aquaculture, poultry). Most of animal agriculture finds itself somewhere between the extremes, making it easy to forget to look at problems in both ways.

Data Types: Qualitative and Quantitative

Data are numbers—weights, counts, heights, speed—that are collected so that decisions can be made on normalcy of an animal or group of animals. Data alone are of little use. Only after they have been collated, and maybe transformed and organized, are they converted into information. As stated earlier, epidemiology is process oriented. Those processes are intended to turn data into information.

Data are classified into three general categories that are not always cleanly differentiable. The type of data used is important because different analytic techniques are appropriate for the different types of data. The two

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broad categories for data are either *qualitative data* (categories and ranks) or *quantitative data* (counts and continuous measures). A special case—*dichotomous data*—is discussed at the end of this section.

Qualitative Data

Also known as categorical or class data, qualitative data are generated when a variable or process can be grouped only into certain distinct classes or categories (hence the term *categorical*). The categories that are simply names are called *nominal data*. The categories that depict an inherent ordering among categories are called *ordinal data*.

Qualitative Data Type 1: Nominal Data. Classes such as animal breed or sex are nominal. They are names. Ranking Angus over Holstein over Zebu over Brown Swiss makes no sense. Likewise, the labels "gilt," "sow," and "boar" form a nominal classification. The quick test to check whether nominal data are being used is to change the names to something unrelated and see if information has been lost. For instance, if the "gilt," "sow," and "boar" set of classes was changed to "apple," "fork," and "shoe," nothing has been lost. The new names still differentiate the groups. Granted, "gilt," "sow," and "boar" are recognized as being swine, but changing them did not affect any ordering or ranking inherent in the class names. They are, therefore, nominal data.

Nominal data can be described as only frequencies, percentages, or counts. Averages mean nothing; saying the average animal is three fourths steer and one fourth cow is meaningless. However, saying a 1000-head farrow to finish hog farm has 25% sows, 15% gilts, 50% growing-finishing pigs, and 10% boars makes sense. Some statistical tests are designed to work with frequencies and percentages.

Qualitative Data Type 2: Ordinal Data. Qualitative categories may have an innate order or ranking quality to them. For instance, the following show an ordering tendency: beef cattle frame rankings of 1, 2, and 3; California Mastitis Test findings of negative, trace, 1, 2, and 3; and bird age classes such as poult, juvenile, and mature. However, there is no claim that a cattle frame size of 4 has twice the "frame" of a 2 or that the age difference from poult to juvenile is the same as the difference from juvenile to mature.

This is the distinction between ordinal data and true quantitative data: The ranks simply allow practitioners to "line up" the data points. No information exists on the relative distances between ranks. The quick way to see if ordinal data are being used is to change the classifications to "tiny," "small," "medium," and "big"—or any other series of descriptors (hot to cold, light to heavy)—and see if information has been lost. For instance, Dairy Herd Improvement Association (DHIA) records are often reported for cow age classes of "lactation one," "lactation two," and "lactations three and higher." If simple names such as "apple," "fork," and "shoe," were assigned, as used before for nominal data, the inherent ranking of lactation number would be lost. However, if they are called "young," "middle," and "adult," the ordering is maintained. This makes the classification ordinal in nature. Ordinal data can be reduced to nominal data, for instance, by describing birds by type of vaccine used (i.e., vaccine A versus vaccine B) and thereby removing the ranking information contained in measures of age category.

Ordinal data can be described as frequencies, percentages, and counts. Some *nonparametric* statistical procedures also exist that allow working with ordinal data and getting more information out of them than from nominal data.

Quantitative Data

Quantitative data are also known as *continuous* or *interval* data. The main characteristic of this class of data is that the thing being measured ostensibly could be measured always in a more exact manner; it is plausible to describe something as being partway between two classes. For instance, in agriculture the ages of females are often recorded as their age, in years, at the most recent parturition. In a goat herd, a set of five does could be listed as being 3, 3, 4, 6, and 7 years old. Had a more refined or precise measure been chosen, such as months of age at most recent parturition, those same five does might be listed as having ages of 22, 27, 46, 78, and 89 months. Technically, the animals' age could be measured in days (i.e., the oldest doe turned out to be 2719 days old at her last kidding) yet reported in years, thus giving a value such as 7.45 years or even 7.448219178082 years. It does not matter if the extra precision is useful (knowing a goat's age to 12 decimal places is of doubtful help), but it is plausible. In addition, the individual indices, such as 1, 2, or 3 years, must represent the same interval or distance for data to be quantitative. Therefore a goat that is 3 years old is considered equidistant in age from a 2-year-old and a 4-year-old. With equal intervals a calculation of average age of 4.6 years for the does previously mentioned makes sense. Doing this with DHIA parity ages would be an error. Whereas parity 2 animals indeed have had twice the parturitions as parity 1 animals, the fact that all animals parity 3 and higher together are combined makes this noncontinuous, and therefore an average would be in error. This equal interval quality makes continuous data different from ordinal data.

A special case of interval data is called *ratio* data. The added quality here is that there is, besides the ordering and distance properties of interval data, a meaningful zero point (meaningful in that a zero means the absence of the characteristic in question). Although the two commonly used temperature scales have a zero level, that zero is defined by convention, not as the absolute absence of heat. In both the Celsius and Fahrenheit systems, absence of heat occurs well below the designated "zero" point. The Kelvin temperature scale, on the other hand, has a meaningful zero point, since it is defined as the absence of energy. Therefore Celsius and Fahrenheit temperatures are not ratio scales, but Kelvin temperatures are. Measures based on counting, weight, age, and distance are ratio scales because a zero weight-age-height has meaning. In an interval (nonratio) scale relative magnitudes of difference must be described carefully because the "zero" level does not describe the absence of the character under investigation. Therefore a beaker of water at 80° C should not be described as being "twice as hot" as a beaker of water at 40° C. However, going back to the goat herd example, it makes sense to claim that an 8-year-old doe is twice the age of a 4-year-old doe.

Continuous data can be reduced to ordinal data or to nominal data. This is done all the time. Practitioners may measure pounds (or kilograms) of pig sold per sow per year (a continuous variable) yet run an analysis of average piglet weight gains by categorizing the females into "low producers," "moderate producers," and "high producers" (creating ordinal data) instead of by actual pounds of pig weaned per year. Also, the sow herd can be divided into family or genetic groups, making the classification a nominal category.

Continuous data can be subjected to the full armamentarium of statistical processes for description and analysis. The only thing that limits this is the distribution the data take, for most statistical tools make assumptions about the underlying distribution of the data being evaluated.

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Qualitative or Quantitative: Dichotomous Data

A dichotomous variable has only two classes, such as yes-no, success-failure, or male-female. Some dichotomies are based on a natural ordering or preference. For instance, passing an examination is usually preferable to failing it. However, many dichotomies, such as gender, offer no natural reason for claiming an inherent ordering. Nonetheless, because there are two and only two categories, dichotomous data can be treated as ordinal, at least. Although a ranking may not be inherent, ranking female before male or male before female satisfies the mathematical requirements for ordinal data. In addition, since only one interval is to be managed, dichotomous data can be mathematically treated as interval data—even though the outcome may not make much logical or physical sense (i.e., average gender in a sheep flock may be 0.95 if the dichotomy were male = 0, female = 1, and the flock had 20 ewes for each ram). Hence, treating dichotomous variables best entirely depends on the questions asked and the nature of the classification. The mathematics is not a limit; the logic is.

The boundaries between ordinal and continuous are not as clean as many analysts would like to think. Some measures can be argued reasonably as representing one data type or the other. For instance, if steer carcass weight is categorized in units of pounds, it is obviously continuous. However, if carcasses are classified as either "big" or "small," the measure is just as obviously ordinal. What about weight classes in 50-kg increments or in 300-kg increments? What if they are just called "above average" and "below average"? At some point, even though the basic measure is continuous, categorizations are pushed from continuous to categorical types of data.

What about body condition scores in use in several species of animals? Some workers consider them strictly ordinal, because a condition score of 2 is not half the condition of a score of 4 and because a body condition score of 2.66788 claims a level of precision that does not exist. Hence, by this argument, body condition scores form an ordinal scale, not a continuous scale. Others, however, argue that this lack of multiplication is simply a consequence of a measuring tool that does not go to zero (i.e., makes the data type interval data but not ratio data) and that the intervals of the weight differences from a score of 2 to a score of 3, 3 to 4, and 2.75 to 3.75 are actually fairly constant in the standardized systems, which makes them appropriate for interval statistics. A cursory Medline* search for the *Journal of Dairy Science* over the period from 1994 through the first half of 1999 in which the term "body condition" was used either in the title or as a keyword (and were not review articles) yielded 11 citations. Of those, one study treated body condition as a strict ordinal variable in the analysis (Duffield et al, 1999), seven articles (five separate research teams) treated body condition scores strictly as continuous-interval variables (Ferguson et al, 1994; Hady, et al, 1994; Waltner et al, 1994; Domecq et al, 1995; Flamenbaum et al, 1995; Domecq et al, 1997a,b), and three articles (three separate research teams) reported or treated body condition scores as both continuous and categorical variables in the analysis (Waltner et al, 1993; Gallo et al, 1996; Heuer et al, 1999). Hence, it appears that reasonable people (as well as journal editors and reviewers) have agreed to disagree on the true nature of body condition scores.

*Medline, PubMed, National Library of Medicine, National Institutes of Health, Washington, DC. Available at: http://www4.ncbi.nlm.nih.gov/PubMed. Accessed October 12, 2000.

The apparent contradiction just mentioned is a false contradiction. The argument is not about the measurement of relative body condition but whether the measuring tool being used to capture body condition is precise enough to form continuous data. This is the crux of the debate: At some point, the ability to precisely measure something becomes so coarse that the resulting categories simply rank individual measures but do not give sufficient information to warrant the claim that a reliable absolute difference exists between classes. The argument does not stop there. In addition, the practitioner could ask reasonably if body weight, let alone body condition, is actually an accurate measure of total body energy stores. Technically, it is one part of the equation; estimates of the proportion of that weight composed of bone, protein, fat, gut-fill, and water should be available to accurately measure changes in body energy stores. But they are not. Even though body condition scores appear to be crude proxies of a somewhat useful measure, they have turned out to be quite helpful in making decisions about cattle rations and management, despite the inability to determine the most appropriate way to define the data.

Data Distributions: Not All Data Are "Normal"

Most people assume that if something is measured on a number of individuals (milk production in cows or starting salaries for new graduate veterinarians), the numbers are going to cluster around some value and trail away fairly evenly on both sides of the cluster. This is a decent working definition of a normal distribution: the typical "bell curve." But not all measures actually come in nice, clean, normal distributions. Some cluster at a fairly low measure and have relatively long "tails" that identify a few individuals with very high values. In standard graphical depictions, these kinds of data are described as being skewed to the right—the higher values on most charts move to the right. A distribution showing a long tail at lower values is "left skewed" for similar reasons.

Fig. 2-3 depicts actual Holstein heifer heart girths measured in centimeters. This is an example of how real data can take a basically normal distribution. It is not perfect, but for 39 measures, it is about as close as can be expected. A few

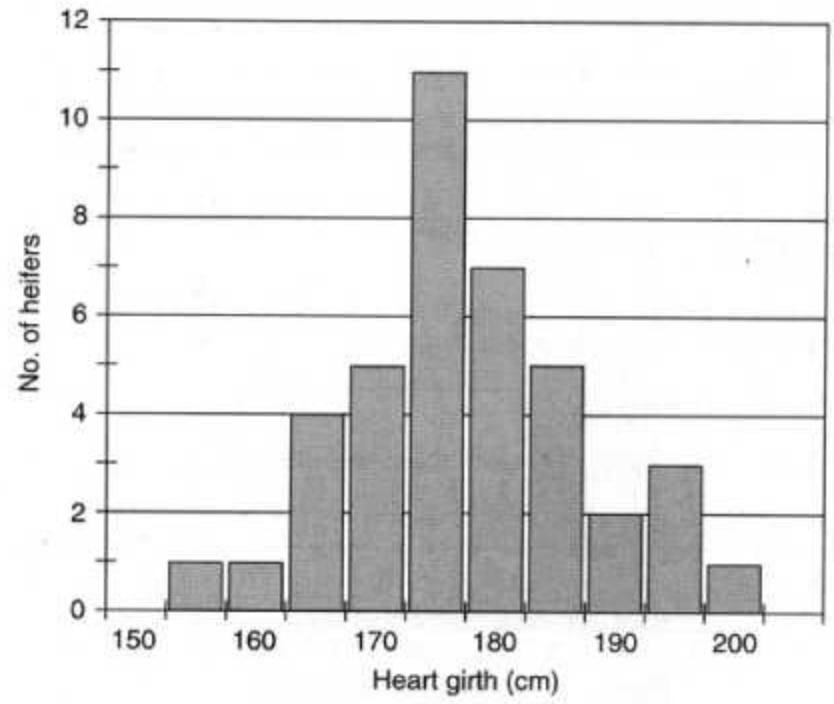

FIG. 2-3 Holstein heifer heart girths in centimeters. Example of relatively "normal" distribution from biological data. Average girth = 176 cm, standard deviation = 4.0 cm, median = 175 cm; count = 39.

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simple tests to determine whether a set of data is fairly normally distributed are as follows:

1. Mean and median are close to the same value. For the data in Fig. 2-3, the mean heart girth is 176 cm and the median is 175 cm.
2. Two standard deviations (SDs) above and below the mean do not exceed the actual distribution. For the data in Fig. 2-3, a 2 SD range beyond the mean is 156 to 196, well within the distribution's actual range of 153 to 198.

Fig. 2-4 illustrates a highly skewed data set, representing the time, in days, following weaning for a group of 671 sows to come into estrus. This is an example of "right skew" to the data. If the criteria just mentioned are used to determine whether a data set is normally distributed, this data set fails for the following reasons:

1. The mean for this data set is 28% larger than its median (6.4/5.0 = 1.28).
2. A 2 SD range above and below the mean exceeds the overall distribution (−5.4 to 18.2).

In addition, by going into negative numbers, the 2 SD range creates illogical values. Hence, with only the descriptive data, we recognize this data set is not normally distributed.

A general assumption can be made that biological data are often relatively normally distributed, whereas data in which people affect the outcome (e.g., management variables) are usually skewed. For example, Ruegg (1997) describes certain dairy data as being "often skewed" (days open, days to first service, age at first calving, somatic cell count, number of breedings) or as "usually normal" (days dry, fat corrected milk production, milk per cow per day, peak milk yield, pounds of fat or protein). Of course, this is not always true; both Figs. 2-3 and 2-4 would be considered "biological" data. When in doubt, the veterinarian should look at the data.

Other, more statistically robust, methods exist to determine if a distribution is or is not normal (Snedecor and Cochran, 1989). The terms used are *skewness,* which has been discussed in this section, and *kurtosis,* which refers to how "pointed" a distribution is; a highly kurtotic distribution shows little variability (hence, it looks very "pointed" in a graph), whereas a distribution that is not very kurtotic appears to rise and drop slowly (hence, it looks fairly flat and widely distributed). Statistical tests for skewness and kurtosis are not examined here; they are not used a great deal, and, as demonstrated in Figs. 2-3 and 2-4, often just looking at the data suffices (Altman, 1996). The reader simply should be aware that they exist so that, if uncertainty still remains, normality can be tested after the distributions are seen.

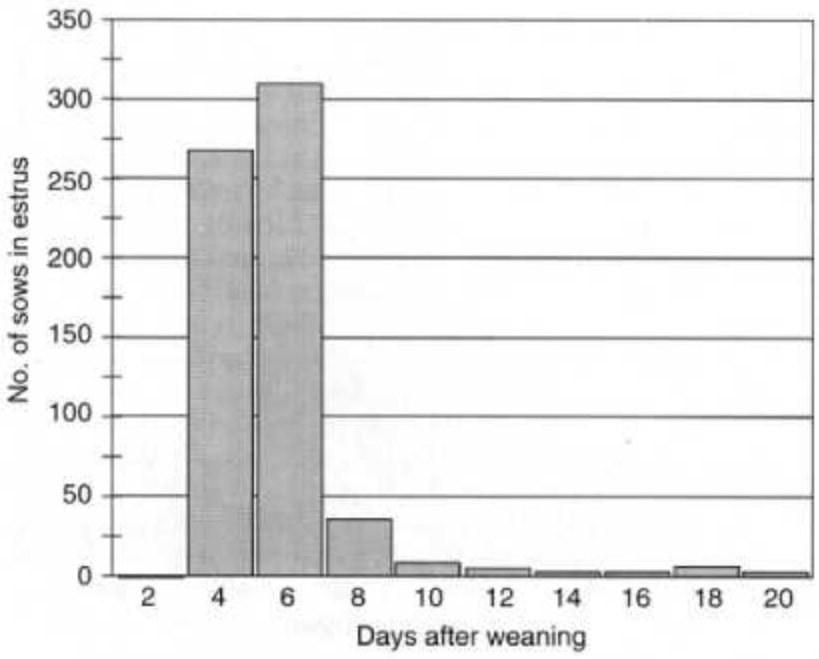

FIG. 2-4 Distribution of first estrus in sows following weaning. Example of highly skewed (right skewed) biological data. Average days to estrus = 6.4 days, standard deviation = 5.9 days, median = 5.0 days; count = 671.

RATIOS, PROPORTIONS, AND RATES

A program cannot be designed, a strategy operated, or outcomes of actions determined without measurement of the breadth and depth of a disease's hold on a population. Hence, a fundamental aspect of both the descriptive and the analytical realms of epidemiology is to quantify or measure the *occurrence of illness* in a population, for it is one of the first steps in understanding the disease being studied. Measurement of disease occurrence is an integral part of determining the impact of the disease in the population, the possible mechanisms of the spread of the disease in the population, and the possible implementation and effectiveness of any control programs.

This section looks at one of the major tools used in animal health, whether in descriptive or analytical activities: establishing occurrence of events in terms of ratios, proportions, and rates.

Ratios, Proportions, and Rates: Definition and Components

Ratios

A *ratio* is expressed as a/b (where "a" is *not* part of "b"), or "a" divided by "b," where "a" and "b" represent counts of two mutually exclusive groups. For instance, an animal cannot be both a "lactating cow" and a "steer," nor can an animal be both "diseased" and "nondiseased." When speaking about a ratio, the phrase "x *to* y" is usually used, indicating that "x" is not part of "y." A ratio is meant to relate the relative size or magnitude of the two exclusive groups. Some examples of typical ratios follow:

1. The feed conversion ratio for a swine-finishing farm is 2.4 to 1. For every 2.4 units of feed consumed, the pigs grew 1 unit. Note that a ratio need not be in similar units; the feed intake could be measured in calories of mix and pig growth as kilograms of meat marketed.
2. Of 314 piglets born in the last month, 15 were stillborn. The ratio of stillbirths to live births in the farrowing house was, therefore, 3:60, which reduces to 1:20. That is, for every 20 live piglets born in this house, 1 more was delivered dead. Again note the exclusiveness of the two frequencies; stillbirths cannot be live births.

Proportions

A *proportion* expresses a fraction in which the members of the group in the numerator (for instance, the number of animals with a disease or condition) are included in the group comprising the denominator (the population at risk). When speaking about a proportion, the phrase "x *in* y" is usually used, indicating that "x" is a part of "y." The difference between a proportion and a ratio is as follows: A ratio requires mutually exclusive categories, whereas a proportion requires one to be a subset of the other. A proportion cannot take on a value less than 0 or greater than 1, and it may be multiplied by 100 to give a percentage.

A proportion can be converted into a ratio (or vice versa) by subtracting the numerator from the denominator (or the reverse). However, this does not always make sense. For instance, in the pig feed conversion example just mentioned,

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combining feed intake calories with kilograms of marketed meat makes no sense. Typical proportions might be as follows:

1. The proportion of bulls in a cow-calf herd is 4/64 (i.e., 4 bulls out of a herd of 60 cows and 4 bulls), or 0.063. Multiplying this by 100 gives the percentage of bulls in this herd: 6.3%.
2. Of 26 mastitis cases on a dairy, 22 resulted in a full recovery, a proportion of 0.846. Therefore the percentage of mastitis cases that were "cured" was 84.6% ([22/26] × 100).

Rates

Rates are proportions that work with a specific time period. A rate shows the relationship between a group undergoing an event (e.g., disease or trauma) and a defined population at risk, both evaluated over a specified time period. The numerator is the number of affected individuals in a given time period, whereas the denominator is the population at risk over the same time period. The following could be a few typical rates:

1. In a cow-calf herd, 45 of 60 cows calved in the first 90 days of the calving season. The 90-day calving rate is 45/60, or 75%. In the terms mentioned previously, calving is the event of interest. In the given time period of 90 days, 45 animals underwent the event of calving.
2. A 2000 sow herd yielded 751 animals positive to porcine reproductive and respiratory syndrome (PRRS) on a herd test. The rate of seropositive animals on that day was 751/2000, or 38%. Here the time period is only 1 day; in fact, it is the time taken to blood-test the herd.

Rates and Ratios of Animal Health Importance

Prevalence and Incidence

Disease occurrence proportions, rates, and ratios either describe situations at a point in time (e.g., prevalence, as in the previous PRRS example) or describe events over time (e.g., incidence, as in the previous farrowing house stillbirth example above). It is easy to confuse them.

Prevalence describes what proportion of the population has the disease at one specific point in time, or the proportion of the number of cases observed compared to the population at risk at a given point of time. *Prevalence refers to all cases of disease observed at a given moment within the population at risk.* For example, suppose a veterinarian is asked to investigate a suckling calf pneumonia problem in a beef herd. The veterinarian finds 24 calves in the less-than-30-day age group on the day of the visit. Of these, 8 are showing signs of respiratory distress consistent with pneumonia. On this day in this herd, then, the prevalence of pneumonia in calves less than 1 month of age is 8/24, or 33%. Prevalence offers a "snapshot" or photograph of the disease state.

Incidence measures, on the other hand, describe the frequency of new cases that occur during a specific period of time. *Incidence refers to new cases that have occurred during a specific time period for the population at risk.* For example, if a practitioner goes to a goat dairy and finds that, from last month's visit to this month's visit, 7 mastitis cases arose out of the 35-head milking herd, the monthly incidence of mastitis in the milking herd would be 7/35, or 20%. Incidence, then, offers a "movie" of the disease state.

One reason why prevalence and incidence get confused is because, essentially, prevalence depends on both the disease incidence (the "flow" of animals from one state to another) and the average duration of the disease (how long an individual remains in the diseased state). A change in prevalence may be a result of a change in either incidence or duration. For a given incidence rate, the prevalence will be higher if the duration of the disease is longer. The prevalence is affected by the mortality rate of the disease, since this affects duration. A lower prevalence results if the disease is often quickly fatal, such as in rabies. However, in a chronic disease situation such as Johne's disease, improvements in case survival due to the implementation of a new treatment protocol could end up actually *increasing* the prevalence of Johne's, even if the incidence went down!

Fig. 2-5 shows how, at equal rates of transmission, the overall disease prevalence increases in an almost counterintuitive manner with increasing duration of disease in any individual. Hence, a better, successful, disease control program may well cause the overall prevalence of that disease to go up.

In epidemiology, the study of the flow of cases from the disease-free state to the disease state is the main area of interest. This is the definition of incidence. Incidence rates, therefore, rather than prevalence, are usually preferred in epidemiological studies because prevalence does not convey the true magnitude of the disease in the study population. There are several important, standard, incidence measures: *cumulative incidence rate, incidence density rate, attack rate,* and *case fatality rate.*

Cumulative Incidence Rate (CIR). The CIR is defined as the proportion of a fixed population that becomes diseased in a stated period of time, or the proportion of healthy individuals who get the disease during a certain period. The CIR is a measure of the average risk, that is, the probability that an individual would develop disease in a specified time period.

As an example, suppose on a swine farm the practitioner followed piglets for one 6-month period—one rotation on the farm. If, during this time, 144 piglets were born, and 36 fit the case definition of neonatal diarrhea, the cumulative incidence rate of the disease over a 6-month period would be 36/144, or 25%. This does not mean that 25% of the pigs are expected to be diseased, but that a piglet born on this farm has a 25% chance of getting neonatal diarrhea in the first 6 months.

Incidence Density Rate (IDR). IDR is a measure of the speed of disease occurrence in a population. It is defined as

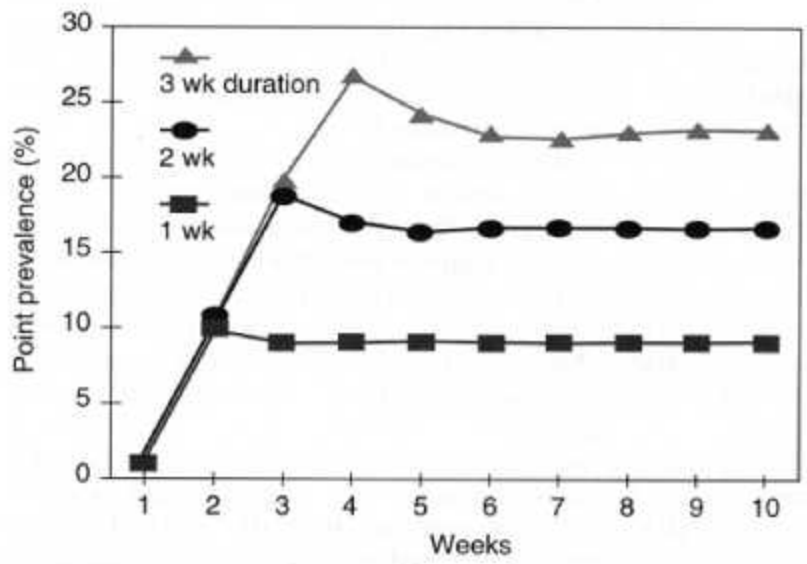

FIG. 2-5 Hypothetical model of a disease indicating how increasing the duration of clinical signs, in the face of no change in actual incidence, causes the prevalence of the disease to increase. This assumes no immunity or mortality from the disease, with a 10% incidence per week.

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the number of newly diseased individuals divided by the sum of the time periods of all individuals in the population who remain disease free. The denominator of the IDR is a combination term representing "person time," "animal time," or "population time" (animal years, calf months, piglet days, etc.); in other words, it is the sum of disease-free time for all the individuals in the population. This inclusion differentiates cumulative incidence from incidence density: *The cumulative incidence is a snapshot of the proportion of individuals affected, sort of an average risk of disease of a given period, whereas incidence density, because of its time sensitivity, yields a measure of an individual's risk, per unit time, of getting the disease within a period.*

For instance, in the swine unit mentioned previously, if the 144 piglets are followed over the first 4 weeks of life (instead of over the 6-month cycle), and none of them become sick, the denominator would be 144 × 4, or 576 piglet weeks. Half that number of piglets followed twice as long would give us the same 576 piglet weeks. So IDR can be used to follow different sized groups for differing times, and still provide comparable measures of disease risk.

The above example can be extended further. Suppose 36 piglets become ill in the first 4 weeks of life, so they could not be used in the denominator. The 108 nondiseased piglets would be fine—they contribute 4 × 108 weeks, or 432 total, to the denominator. Suppose 20 of the 36 became ill on day 10, and 16 became ill on day 18. The 20 would contribute 20 × (10/7) weeks of time (the term "10/7" is merely a way to convert 10 days into "x" weeks), and the 16 would contribute 16 × (18/7) weeks, or about 29 weeks and 41 weeks, respectively. Hence, the total piglet time in this study would be 432 + 29 + 41 weeks, or 502 total. Since 36 animals became diseased, the incidence density rate for diarrhea is 36/502, or 0.072 cases per piglet week. Over a 4-week period, then, each piglet has a 29% (4 × 0.072) chance of getting diarrhea. Table 2-1, option C, shows this calculation.

Calculations done the way just shown are a pain, to be sure. They are labor intensive and assume the farm has records that support that degree of precision. Many do not. What should be done? Estimates can be made.

Calculating Alternate Estimated IDR Population-Times. Suppose, for example, the farm previously discussed could not show with any real precision when the piglets became ill. Two methods that provide an estimate of time at risk are (1) taking a census of the population in the middle of the period and assuming that is an average weekly population, or (2) counting how many piglets existed at the start, how many existed at the end, and taking the average of those figures. Either way, those values are multiplied by the number of periods to get the estimates.

Option A in Table 2-1 shows the method of taking the middle-period census, which overestimates the incidence density by underestimating the total risk weeks. By averaging the starting and ending populations, the analyst underestimates the total incidence density by overestimating total risk weeks. In this example, neither estimate is too far removed from the actual calculation (option C). But this is not guaranteed to always happen; sometimes the estimates can be way off.

Attack Rate. Attack rate, another specific type of incidence measure, measures morbidity (illness) and is commonly used in outbreak investigations. It is calculated as the number of animals affected divided by the number of animals exposed. Attack rate is different from CIR because it looks only at the exposed group, not the whole population at risk. If calves in a veal barn have respiratory mycoplasmosis, the entire population is exposed, making the two calculations the same. However, if displaced abomasums following calving is sought, only the recently calved animals might be considered exposed, not every cow on the farm.

Here is an example of an attack rate: After 4 days of exposure to a diseased animal at a show, a group of 15 4-H steers suffered 6 cases. The attack rate would be 6/15, or 40%.

Case Fatality Rate. Case fatality rate, a specific type of incidence rate, is the proportion of affected individuals who die from the disease. In the piglet neonatal diarrhea example, if 3 of the 36 affected piglets died as a result of the diarrhea, the case fatality rate would be 3/36 = 0.083, or 8.3%. The case fatality rate is usually associated with the seriousness or virulence of the disease under study.

TABLE 2-1

*Example of Different Methods to Ascertain Incidence Density over 4 Weeks**

Time (wk)	Start Day	Start Pop	End Day	End Pop
1	1	144	7	144
2	8	144	14	124
3	15	124	21	108
4	22	108	28	108

A. Count at mid-period and multiply by number of weeks in period†

Mid-period	=	14 days		
Count at mid-period	=	124		
Count × 4 wk	=	496 total risk wk		
Incidence density	=	36/total risk wk	=	0.073
		Risk over 4 wk	=	**29.0%**

B. Take average of starting and ending counts and multiply by number of weeks†

Starting pop.	=	144		
Ending pop.	=	108		
Average pop.	=	126		
Count × 4 wk	=	504 total risk wk		
Incidence density	=	36/total risk wk	=	0.071
		Risk over 4 wk	=	**28.6%**

C. Count at risk days for all piglets and divide into number of cases†

Risk week for nondiseased	= 108 × 4	= 432
Risk week, disease @day 10	= 20 × (10/7)	= 29
Risk week, disease @day 18	= 16 × (18/7)	= 41
Total risk weeks	= Sum	= 502
Incidence density	= 36/total risk wk	= 0.072
	Risk over 4 wk	= **28.7%**

*Data: 144 piglets at start, 20 diseased on day 10, 16 diseased on day 18.

†Demonstration of three methods to calculate population time at risk for a swine neonatal diarrhea example. Options A and B are means of estimating population time at risk when the records do not allow for full accounting. Option C is the actual counting of risk.

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Crude Versus Specific Ratios, Proportions, and Rates

Disease measures are often referred to as either crude or specific. *Crude* measures are derived from population totals (i.e., total animals lost, cases per year in a herd). They are relatively easy to compute and to explain and may represent the best data possible, but they ignore potentially important influences such as host or management factors. *Specific* measures approach the same topic, but they look at group breakdowns within the population (i.e., age-, sex-, or use-specific rates), limiting the view to only the special group of interest.

Crude rates should be used with care when herds or regions are compared, because for crude rates to work the underlying populations must be the same. This rarely occurs. For instance, suppose two southern U.S. dairies report cystic ovarian disease (COD) rates over the month of April. Herd A (an intensively grazed, grass-based dairy) reports a crude rate of 10%, whereas herd B (a confinement-reared dairy) reports 15%. Is herd A truly a "better" herd? Should the manager of herd B be penalized while the manager of herd A gets rewarded for their relative performance?

Suppose the grazing herd calves in late winter to take advantage of the spring grass growth, so the majority of breeding occurs in the spring. The confinement herd calves all year around to maximize its efficiency of facility and personnel use. Because of this, the majority of early breeding (i.e., without reproductive problems) animals in the breeding group for the grazing herd are accounted for in April's figures. The confinement herd, however, because of the distribution of lactation lengths through the herd, has "no problem" cows as well as "problem" cows. These are different stages of lactations and, therefore, different populations. Hence, the monthly crude figures do not tell much and could be misleading. A breakdown of the two herds by stage of lactation helps, as shown in Table 2-2.

The stage of lactation profile of each herd should be noted as greatly affecting the crude rate. Because most of the cows in the intensively grazed herd are in early lactation, the lower rate for that specific group predominates. The same group in the confinement-reared herd, however, has a lower specific rate for COD. However, since the confinement herd practices year-round calving, its lowest rate subgroup comprises only about half the total herd and has a much lower impact on the resulting crude rate.

The dissimilarity in the crude rates occurs because the unique demographic structures of the two herds confound the outcome, yielding rates that are misleading. Controlling for that demographic disparity by using specific rates allows for much better comparisons. Needless to say, when decisions are being made on where to apply program dollars and personnel, the importance of specific rates had better be recognized before effort is allocated! Two different populations exist here; crude rates should be avoided.

TABLE 2-2

*Comparison of Crude and Days-in-Milk Specific Rates for Cystic Ovarian Disease (COD) in Two Hypothetical Dairy Herds**

	Cystic Ovary Statistics (per 100 Cow Days)			
	Grazing Herd		Confinement-Reared Herd	
Days in Milk (DIM)	Count	Rate	Count	Rate
All (in April)	150	10.0%	475	15.0%
1-100	125	5.5%	238	4.1%
101-200	25	32.3%	237	25.8%

*The crude rates suggest the confinement-reared herd has nearly 50% more COD than the grazing herd. However, when stage of lactation is considered, the confinement herd can be seen to have a lower incidence of COD in both DIM categories. Therefore the grazing herd's predominance of cows in the lower DIM class gives the impression that it has fewer COD problems.

STATISTICS FOR PRACTITIONERS: HOOD-OF-THE-TRUCK FIELD TECHNIQUES AND COMPUTER-ORIENTED ADVANCED TOOLS

What Statistics Do: Some Definitions and Caveats

What Statistical Methods Do

The primary role of statistics is to document the existence and degree of difference in data. Statistics allow for separating the events in life that likely are due to chance from those events that likely are due to some action or characteristic of interest. Statistics as a discipline carries a great deal of mystique. It need not be that way.

Repeat Measures and the Unit of Interest

Assumptions in statistics should be approached carefully. Overstepping a basic assumption can invalidate a procedure. It is analogous to a practitioner allowing a set of blood tubes to sit on the dashboard of his or her vehicle for a summer day before submitting them to a lab. The laboratory assumes the specimen was handled properly; because it was not, the results will be highly questionable.

In veterinary medicine, caution should be used in instances in which *repeat measures* (i.e., using an animal as its own control) are used or in which the appropriate *unit of interest* is easily confused with another, inappropriate, factor (e.g., in a mastitis study is the "cow" or the "teat" the unit of interest?). Most statistical procedures assume that the groups being compared are independent. When repeat measures are used, they are not. Repeat measures occur when a difference in milk production on a dairy is sought after a ration is changed. The same thing is being measured, at a different time, on the same animals. Similarly, when a new vaccine is tested in two pens of 100 steers at a feedlot, and the vaccine is given to one pen but not the other, 200 separate units of interest do not exist. There are only two, because both the animals and the treatments are clustered in pens.

An *experimental unit* is the smallest independent component that could receive a separate treatment, and it often determines the smallest unit over which a study can be analyzed. Therefore, if the experimental unit (in the previous vaccine trial example, the experimental unit is the pen) groups individuals, the veterinarian cannot analyze to the individual level (McDermott, 1994). In such cases, with only one experimental unit and one control, no claim can be made regarding within-treatment variability and, hence, the statistical significance of differences observed between animals within either group.

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P-Values

The term "$P \leq .05$" is commonly used in describing the statistical significance of some finding. What does that mean? Basically, it means that a 5% chance exists that the differences described (or effect seen) could be due to entirely random variations in the data. Which level of "*P*" is best is up to the practitioner. There are a number of stories about where the infamous "$P \leq .05$" originated. I do not know which is correct, but none end with the choice being made for any scientific reason.

One way to look at statistical significance follows. Suppose two treatments are being analyzed. One is a successful standard treatment (colostrum feeding, for example), and the other is an experimental procedure (vaccinating the newborn, for example). This is truly a life-or-death situation, and the choice is to go from a successful procedure to an unknown one. In such a case, it is reasonable to require the new process to be obviously much better before the choice is made. Hence, choosing a .01 "*P*" value may be appropriate; quitting the standard treatment requires being sure the differences claimed in a research trial were not simply chance events. If, however, the choice is between two non-life-threatening processes, and the standard treatment is not that good, a much higher "*P*" value—say .1 or .2—could be chosen validly. The importance of the "*P*" value level is related to the importance of the decision.

Furthermore, the purpose should be remembered. If the work is intended to be published in *Science* or *Nature*, the practitioner had better have exceptionally low "*P*" values. Big-league academic journals tend to use them as an index of quality of work and relevance of outcomes. If, however, a decision is being made for a client, and that decision *must* be made soon, the practitioner may not be able to afford the often long time required to generate enough cases, data, or experience to get "*P*" values much below .2. A "*P*" of .2 means 80% certainty the effect is real; 4 to 1 odds are pretty good odds in real life!

Association Versus Causality

Statistics is an inferential discipline; its procedures identify associations that are not likely to be due to random chance. By no means, however, do they prove causation. Therefore small *P*-values should not be used to support the idea of causation. That is the responsibility of the understanding of the biology or flows of the situation under question. Even if a causal relationship exists, however, the statistical methods used do not explain which thing caused which. Again, this is a role for understanding of the system.

Imposing a false correlation between two variables can cause problems. For instance, when evaluating a clinic's profit, the practitioner may wish to standardize the figures by putting both income and costs on an in-clinic per square foot basis or on a per worker hour basis. This could make the resulting ratios falsely correlated (and therefore possibly show a relationship through ordered statistical processes or regressions) even if no underlying relationship existed.

Why Are Statistical Procedures So Complicated and Counterintuitive? Shortcuts and Assumptions

Anyone who is not a math wonk opening a statistics text is often immediately overwhelmed by the odd mathematics involved. All those symbols (Σ, $\surd$, n!) and Greek letters (μ, α, β, γ) combined with mind-numbing square roots, compound power functions, and multiple levels of parentheses and brackets are enough to put off anyone. But statistical procedures look that way because they are simply shortcuts. Most of the modern statistical theory developed in the late 1700s through the early twentieth century. In those times computation was expensive. In the 1890s a calculator was a human with a pencil and paper; a room of calculators was a room full of people doing nothing but arithmetic. People cost a lot to keep busy. To cut costs and make the system more time efficient, many of the early pioneers of statistical inference developed techniques that, if the underlying assumptions were true, yielded important descriptions of the data. These shortcuts became the modern set of statistical procedures for determining significance and for describing data. Like other shortcuts (such as in a complicated recipe for a soufflé), the final process or set of procedures hides much of the reasoning that went into the final product (Simon and Bruce, 1991).

All statistical tests come with assumptions—normal distributions, random selection of observations, independence of variables, to name a few—because those assumptions allow for taking advantage of the shortcuts. If those assumptions are violated, the shortcuts are handicapped. Sometimes the whole process is completely invalidated. It is analogous to the situation of running blood work. The problems inherent in mishandling blood samples are familiar; as mentioned at the start of this section, if a clot-tube is left on the dashboard of a vehicle over a summer afternoon and then submitted for a chemistry panel a few days later, the value of the results (if any are possible) will be limited. The laboratory analyses "assume" the sample was handled correctly. The laboratory can still check for glucose and liver enzymes, but if the laboratory's assumptions are violated, the outcomes are put in question. As long as the technician can shove the sample into the analytical instrument, some kind of outcome will appear; the test is ignorant of whether the assumed procedure in collection and handling was followed. The same is true for statistical processes. Plugging in numbers will lead to a result. Whether that result is meaningful depends on whether things were done correctly.

Choosing the Correct Procedure

Whereas a number of statistical procedures are feasible only when run on a big computer, and only then after a statistical consultant has organized the data, those procedures are not of much value in everyday, on-the-farm decision making. The statistical procedures demonstrated here fall into two categories:

1. Quick methods needing only pencil, paper, and a calculator, or what can be called "hood-of-the-truck" (H.O.T.) statistics. These are simple procedures requiring only that a couple of numbers be remembered. They have the potential to answer many statistical questions arising from veterinary-generated data.
2. More in-depth procedures suitable for computerized analysis. These procedures are readily available with current spreadsheet software and the many stand-alone statistics programs on the market. They tend to make more assumptions than the previous measures and require a bit more sophistication in setup and interpretation.

Data Form Determines Statistical Technique

Type of Data Determines Choice of Statistical Technique

Which statistical procedure to use and, hence, for which outcome to opt entirely depend on the type of data being used. Most veterinary data come as means with measures of variability, as counts and frequencies, or as "before and after" counts/frequencies. Each type of data has its own specialized analytical techniques.

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Data that come as *means and variability* include the following:

1. Average milk per cow per day ± 1 SD
2. Average work hours per week ± 1 SD, for large animal practitioners
3. The AI technician's average conception rate and standard deviation, over 1 year.

Data arriving as *counts or frequencies* include the following:

1. Proportion of Holsteins coming down with milk fever over a year's time
2. Percent of veterinarians with yearly net incomes greater than $60,000
3. Number of synchronized heifers responding out of a larger group

Data forming *"before and after"* measures could be as follows:

1. Herd average daily gain responses to changes in the ration
2. Client attitude scores following inception of a new in-clinic client management program
3. Rate of serological response after vaccination

"Hood Of The Truck" Statistical Methods

Rapid and Easy Statistics

This section looks at different techniques for testing differences between groups using the previous definitions of data type. The first three techniques fit the "hood of the truck" (H.O.T.) requirements. They must allow for answering a statistical question with a paper, pencil, and calculator—and allow for doing so without memorizing tables of numbers. The second group of techniques relates to more complicated procedures that are offered in spreadsheets and stand-alone statistical programs.

When Data Produce Averages

Z-test confidence interval for the difference between two means. Data in the form of averages and variability are among the most commonly developed data in medicine. Remember that to calculate an average, the data must be continuous data (interval or ratio), not ordinal or nominal. I have found most data concerning averages are best evaluated by using a *Z-test confidence interval* (Hamburg, 1983). The process is demonstrated in H.O.T. Stats Worksheet 1 (Chapter Appendix B).

Other ways exist to look for differences between means. However, H.O.T. Stats Worksheet 1 is about the simplest available. The biggest problem with most tests of means is that they require the data to be normally distributed. Practitioners in veterinary medicine often deal with small enough groups that they cannot claim normality. As the previous section explained, once a data set is determined to be nonnormal, using means and measures of variance to describe that data set is of questionable validity.

The trick to the Z-test confidence interval is that it tests for the *difference between means*. The data actually being tested, the differences between means, are the population that needs to be distributed normally, not the raw measures from which the means were calculated. *It just so happens that means of all kinds of distributions can be taken, one subtracted from the other, and the results can come out approximately normally distributed.*

Fig. 2-6 depicts two hypothetical populations of cows, one of which received a standard teat dip treatment, and the other of which was subjected to an experimental treatment. Whereas both distributions are highly skewed, with most animals in the lower somatic cell count (SCC) range, the animals in the standard treatment appear to have the "better looking" distribution.

Fig. 2-7 illustrates the distribution of differences between means of multiple samples from the two sets of cows depicted in Fig. 2-6. Sixty sets of 10 animals were randomly pulled from each population, and the SCC values for the experimental group were subtracted from the standard treatment group and averaged. The mean and median of this distribution are nearly identical, and a 2 SD distance from the mean (−406 to 35) does not exceed the actual distribution. This distribution fits the previous definition of a normal distribution.

Hence, the Z-test confidence interval statistic can be used to determine if one population has a different average SCC

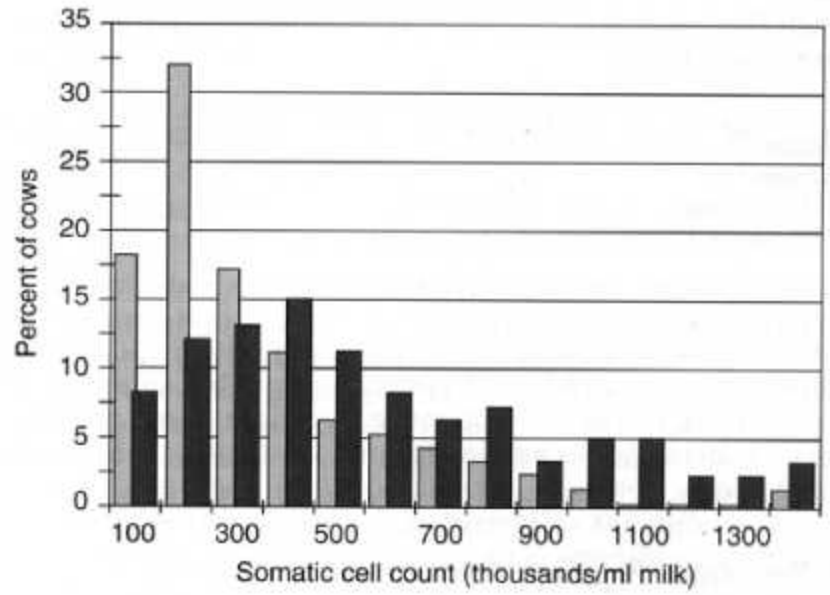

FIG. 2-6 Distributions of two hypothetical sets of cows by somatic cell count. The lighter bars represent those animals whose management uses a standard teat dip. The dark bars represent cows whose management uses an experimental teat dip. Both distributions are right skewed; however, the lighter bars appear to have the preferable distribution from an udder health point of view.

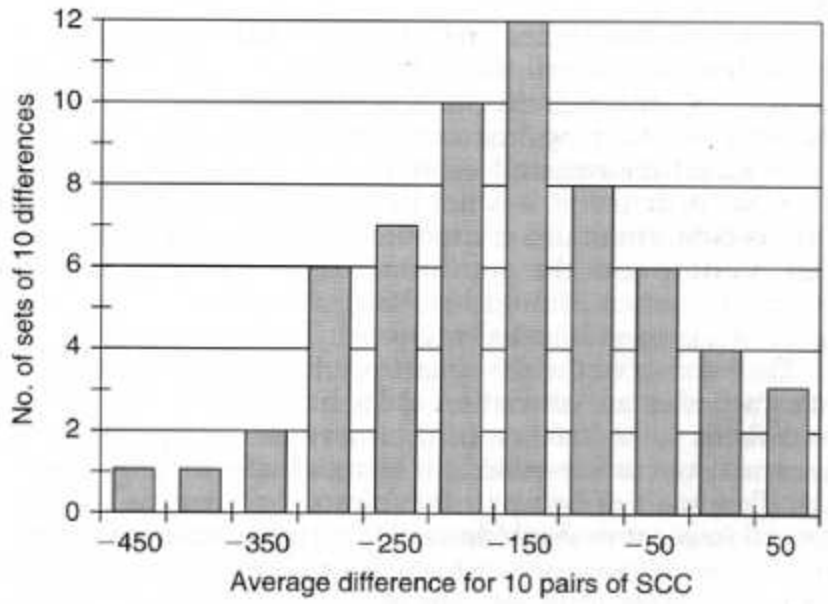

FIG. 2-7 Illustration of relatively normal distribution for the difference between two means, even when the underlying distributions are skewed. At random, 10 observations from each of the two groups shown in Fig. 2-6 were subtracted from each other (standard treatment − experimental treatment) and the differences averaged. This chart represents 60 repetitions of this subtraction and averaging. Mean = −186; standard deviation = 110; median = −180; n = 60. *SCC*, Somatic cell counts.

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than the other. The reader can run the math, but the results are shown below:

	Standard Dip	Experimental Dip
Count	100	100
Average	331	556
Std deviation	236	345

95% CI for difference in means = −230 to −220

Given these results (i.e., zero is not included in the interval), the practitioner can be at least 95% certain that the cows in the experimental group have significantly higher SCC than the cows in the standard treatment group. This difference is likely in the 220 to 230 SCC range. Therefore, based on these data, a client should not be recommended to use the experimental dip.

When Data Produce Frequencies or Counts

Chi-Square Test for Contingency Tables. Another common type of data encountered comes in the form of counts or frequencies. The observations can be from nominal, ordinal, or continuous types of data. Examples include gilts versus sows pregnant, proportion of teats dipped, or number of foals with good versus poor plasma protein levels.

"Count" data are best evaluated using a *chi-square for contingency tables*. The process is demonstrated by using a cattle example in H.O.T. Stats Worksheet 2 (Chapter Appendix C).

Small Sample Sizes and the Chi-Square Test. The requirement that no cell have a smaller value than 5 can raise difficulties. However, this limit is placed by the assumption that the "underlying," or expected, distribution follows a chi-squared distribution—sort of a right-skewed distribution. So, in actuality, it is not the observed data, but the expected data, that must contribute at least five items to each cell. So how does the practitioner figure out what the "expected" numbers should be? First, it must be understood what this process is actually testing.

The version of the chi-square test just discussed is evaluating whether an association exists between the row factors and the column factors. In the previous example, if there were no association—that is, if being a heifer did not change the likelihood of being in the "clean" or "metritis" class—*the cell frequencies should be roughly the same. In fact, since neither is more closely associated with being "clean," each would be expected to have about the same proportion as the grand proportion in the overall population. That is the definition of the expected values.*

Calculating the Expected Values for a Small Sample Size in a Chi-Square Analysis. Suppose a practitioner is working with a dairy client who has problems managing young stock. To help the client's heifer reproduction, the practitioner starts a two-injection, 11-day-interval, prostaglandin synchronization program on 24 heifers. Based on estrus detection, and by rectal palpation at breeding, the client says that only half the heifers responded (and implies the practitioner doesn't know what he or she is talking about). The practitioner visits the farm and wonders if the failure rate was due to a high proportion of thin heifers. A body condition score (BCS) is recorded for each animal in the group of 24, and the practitioner marks down whether the client classified them as being in estrus in the 3 to 5 days following the second prostaglandin injection. Approximately half the heifers appear to have had a BCS of 3 or greater, so that is used as the breakpoint in the analysis of whether being in the thinner group was associated with a higher likelihood of not responding to the prostaglandin program. The following table summarizes the findings:

	BCS ≥ 3	BCS <3	Total
Synchronized	8	4	12
Not synchronized	5	7	12
Total	13	11	24

The thinner animals apparently were less likely to synchronize than the heavier animals (approximately 36% success rate [4/11] versus 62% rate [8/13], respectively). The question, though, is how likely is this apparent difference due to random chance? The problem nicely fits a chi-square procedure, except for the fact that one cell (the "Synchronized" by "BCS <3" cell) has a value less than 5, which could invalidate the chi-square procedure. The expected value for that cell should be examined further, following the above argument.

If no association existed between BCS and synchronization, the proportion of synchronized heifers in both groups would be expected to be the same and, therefore, equal to the overall proportion of synchronized heifers (12/24 = 50%). Since 11 total heifers are in the "BCS <3" group, then 50% of 11, or 5.5, is the expected value for that cell. The other 50% are expected in the "Not synchronized" group. The entire table of expected values follows.

	Expected Values		
	BCS ≥ 3	BCS <3	Total
Synchronized	(0.5 × 13) = 6.5	(0.5 × 11) = 5.5	12 (50%)
Not synchronized	(0.5 × 13) = 6.5	(0.5 × 11) = 5.5	12 (50%)
Total	13.0	11.0	24 (100%)

Since the expected value for the "Synchronized" by "BCS <3" cell is greater than 5.0, it can be used in the chi-square analysis with this data. The following example, provided just to finish the analysis and to show another sample of using the chi-square, walks through the steps from H.O.T. Stats Worksheet 2, starting at Step 4 (Do the Math):

$$\frac{[(8 \times 7) - (5 \times 4)]^2 \times 24}{12 \times 12 \times 11 \times 13} = \frac{31{,}104}{20{,}592} = 1.51$$

The test statistic, 1.51, is less than the chi-square value for 80% confidence. A quick check in a statistics book or in Chapter Appendix A shows this test statistic falls between the value for 70% (1.07) and 80% (1.64). Therefore the practitioner can be at least 70% certain, but not 80% certain, that the lower BCS heifers did not synchronize as well as the higher BCS animals did.

Several authors (Fleiss, 1981; Snedecor and Cochran, 1989) argue that the limitation on cell sizes is likely too strict. Other rules of thumb are that no expected value be less than 1.0, and that over 20% of the actual cell values should exceed 5. Essentially, the smaller the sample size, the more difficult it is to defend *any* statistical procedure.

More Chi-Square Stuff: Statistical Significance Versus Magnitude of Effect (Odds Ratios). Just because something is statistically significant does not mean the overall effect is clinically significant. For instance, if the survival rate of piglets following a new neonatal diarrhea treatment were to be statistically better than that of a standard treatment, yet it improved survival rates by only 1%, the new procedure still may not be recommended. The 2 × 2 tables used in chi square analyses can be used to measure magnitude of effect. Magnitude of effect can be determined in two ways: the relative risk and the odds ratio (OR). The first is valid when dealing with an entire population (all the cows in a herd, for example), and the OR is best for dealing with a sample (a proportion of all the cows in a herd). For all intents and purposes, however,

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the OR can be used in either situation, so the next section focuses on this.

The OR from a 2 × 2 table is simply the result of dividing one diagonal product by the other. In the above synchronization example, it is the following:

$$OR = (8 \times 7)/(5 \times 4) = 56/20 = 2.80$$

This implies the higher body score group was nearly three times more likely to synchronize than the lighter body score group. Methods are available to construct a confidence interval around an OR, but they are not discussed here because they are relatively intensive computationally (and therefore do not fit the definition of a proper "hood-of-the-truck" procedure). Readers who are interested should refer to Fleiss (1981) for those methods.

When Data Produce Frequencies or Counts with Repeat Measures

Sign Test. The sign test is a simple means of addressing effects of treatments or programs when the same animals are measured twice (i.e., *repeat measures*), meaning the group comparisons are not independent. When the average daily gain on a group of pastured steers is measured before and after a worming treatment, the measures are dependent (i.e., fast growing steers from the previous month still tend to be the faster growing steers the next month) and therefore appropriate for the sign test. This can be used on any measure fitting a dichotomous class—yes-no, high-low, big-small, fast-slow, etc.—or anything that has a "better-worse" meaning. Therefore, continuous, ordinal, and even some nominal data forms work with the sign test. The process is shown in H.O.T. Stats Worksheet 3 (Chapter Appendix D).

The sign test assumes little about the underlying data structure. This makes running the test simple. However, some things are lost by simplifying matters. In the example, for instance, the *magnitude of change* in MEMP is unknown. Suppose that the cows that went up in milk production did so by 3%, and that the 26 cows that went down did so by 30%. The sign test would show that more went up than went down, but given the magnitude differences, the ration change should not be kept. Sometimes the best that data allow is a simple sign test, but bear in mind that ignoring the relative amount of change in each group could be an expensive mistake.

MORE COMPLICATED STATISTICAL APPLICATIONS: USING COMPUTER SPREADSHEETS

At Times, Fast and Easy Just Will Not Do

While the three "hood-of-the-truck" techniques cover most of the typical consultant's needs for quick and dirty decision making, they do not address all the questions concerning statistical data analysis. Only a few years ago the only statistical software available were stand-alone statistical programs that cost hundreds, if not thousands, of dollars and may have required programming knowledge to boot. These days any of the major commercial spreadsheets offer a wide array of statistical tests suitable for addressing many of the questions that production medicine veterinarians face. Several of these are discussed, following the same format as before; that is, they are categorized by the type of data being used—data arriving as means and measures of variance, as counts or frequencies, or as before-and-after types. Each of the three examples has a couple of twists, and an additional situation looks at determining if one variable is being driven by another (such as by looking at the association of weight gain and ambient temperature or if milk production and SCCs are related).

When Data Produce Averages: Two-Sample t-Test

When Data Come From Normally Distributed Populations and Independently Selected Samples

This section returns to the example in H.O.T. Stats Worksheet 1 in which the open heifers were believed to be lighter than the pregnant heifers. Suppose the practitioner actually got a list of the animals and their weights and took them back to the clinic. The values could be loaded into almost any of the modern spreadsheets and a statistical test run on them. But which one? When data came as averages with measures of variability, a reasonable test to determine the difference between means is the *Student's t-test*. One spreadsheet method of performing this test using the previous example of weight differences between pregnant and open heifers can be found on Spreadsheet Stats Worksheet 1 (Chapter Appendix E).

The Quattro Pro 8 t-test process, used in Spreadsheet Stats Worksheet 1, should be examined a bit closer. One point to expand on is the section in which a choice is given between *Two Sample with Equal Variances*, and *Two Sample with Unequal Variances* [Step II, B, 5 in the worksheet]. The question here is whether the two samples show significantly different amounts of variability. If they are different, the latter test should be used. Most spreadsheets allow the analyst to run an *F-test* to determine whether the variances can be considered equal. In most cases, given the rough values usually used in veterinary medicine, the two procedures yield essentially equivalent results. For the above example, the t-test procedure assuming unequal variances yields a "$P(T \leq t)$ two-tail" of .18—for all intents and purposes this is equivalent to the prior estimation of .2.

Another part of the process just mentioned is the section in which the analyst can choose <*Alpha*> or <*Difference*> values (Step II, B, 5 in the worksheet). The "Alpha" is simply asking for the *P*-value the analyst is willing to accept. The output will generate the t-value at this confidence level in the lines labeled "t Critical" for either the one-tailed or two-tailed tests. The "Difference" allows the null hypothesis to be changed; that is, whether the difference is hypothesized as zero or some other number. I recommend keeping the null hypothesis at zero; it is standard convention and relatively easy to interpret.

When Data Produce Frequencies or Counts

Two-by-Two Tables: Revisiting the Example of the Rate of Metritis in Heifers Versus Cows. This section returns to the example in H.O.T. Stats Worksheet 2, which examined a significant difference in the rate of metritis in heifers versus cows following a fertility examination at a farm. Frankly, it requires about as much work to run the 2 × 2 chi-square test using a spreadsheet as it does using the "hood of the trunk" techniques. However, the spreadsheet—Spreadsheet Stats Worksheet 2—is useful because it can run a larger chi-square than a 2 × 2 (Chapter Appendix F).

When Data Produce Frequencies or Counts with Repeat Measures, Paired t-Test

When Data Come as Averages in Pairs (i.e., Not Independent Samples) from Normally Distributed Populations. The sign test example used in H.O.T. Stats Worksheet 3 is reexamined in this section. Paired t-tests look at situations in which related items were measured: comparing

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right feet to left feet in a study of hairy heel warts in dairy cattle, looking at weight gain changes following addition of a mineral mix to a pen of feeder pigs, evaluating the impact of preventive medicine programs on several cow-calf farms and the returns to management. These all have some kind of a "before and after" feel. The process is demonstrated in Spreadsheet Statistics Worksheet 3 (Chapter Appendix G). The options for this test are the same as those for the *"Two Sample with Equal Variances"* t-test run in Spreadsheet Stats Worksheet 1.

When Data Produce Continuous Variables in Which One Variable is Likely Dependent on the Other

Sometimes events occur in which an outcome of interest is being "driven" by some factor or event. For instance, the practitioner may suspect a relation between the percent of gilts in a herd and average litter size or average weaning weights, may suspect an association between rainfall and SCCs, or may be told by a client that summer heat is causing decreased estrus detection rates. Is the relationship "real" or not? Is this a true association or just a chance observation? Statistics cannot tell about reality, but they can show the likelihood of that relationship's being due to chance.

Regression compares the variation in one quantity as a function of the variation in another. The outcome variable (average litter size, weaning weights, SCCs, or estrus detection rates) is the "dependent" variable, designated as "Y" in regression terminology. The variable suspected of driving the outcome (percent gilts, rainfall, or temperature) is the "independent" variable, labeled "X" in regression nomenclature.

Regressions tell how much of the variation in "Y" is explained by changes in "X." This is the "R^2" (called "R-squared") value; an R^2 of 0.4 means 40% of the variability in outcome "Y" is accounted for by the independent variable "X." These, however, are the minimal data derived from a linear regression. A few extra steps can help test whether the degree of association or correlation found, and whether the calculated effect, or slope of the line, is significant. The process is demonstrated in Spreadsheet Statistics Worksheet 4 (Chapter Appendix H).

Expansion of Spreadsheet Capabilities. Several third-party spreadsheet enhancement tools are on the market. In general, they operate as modules that allow spreadsheets to perform more complicated statistical analyses. Given the constant evolution of software packages, it makes little sense to go into the subject here. A number of user and support groups for various software or disciplines also exist. Interested readers are encouraged to explore these avenues, including searching the Internet for "spreadsheet statistics," for up-to-date information, software availability, and capability.

BEYOND SPREADSHEETS: STAND-ALONE STATISTICS PACKAGES

Commercial Statistical Software

Many commercial statistical packages exist. In general, they perform the statistical procedures listed in this chapter in a more complete and easier manner than the spreadsheet applications. Most also carry with them numerous diagnostic procedures that allow an analyst to do more and, therefore, to better understand the system being evaluated. For instance, one such program, Statistix for Windows (Analytical Software, Tallahassee, Fla.) was used to evaluate the linear regression problem of somatic cell code versus rolling herd average (RHA) in Spreadsheet Stats Worksheet 4. Figs. 2-8 and 2-9 show several output screens from the program.

Fig. 2-8 displays a typical set of output screens for the SCC code versus RHA problem. It displays the raw data (the window titled "C:\sccvsrha.sx"), a standard linear regression report plus analysis of variance (the window titled "Linear Regression - Coefficient Table), and an illustration of the regression line as it relates to the raw data (the window titled "Linear Regression - Simple Regression Plot"), along with confidence intervals for the prediction of the mean response (the narrow band) and for any single fitted variable (the wide band). Note that most of the data listed in the spreadsheet version are also listed here, except that Statistix uses a different test for significance for the constant. The analysis of variance table (the five-line table at the bottom of the window titled "Linear Regression - Coefficient Table") allows an analyst to gauge the significance of individual items in a multiple variable regression; that is, a regression in which more than one independent variable existed. In this simple case it does not add much to the analysis.

The graphic in the window titled "Linear Regression - Simple Regression Plot" draws the regression line through the data, plus it yields a 95% confidence interval around the regression line (the curved, fairly narrow band). This is useful for putting some range understanding into the regression evaluation. For instance, given these data, the analyst can be 95% confident that, should the herd achieve a reported SCC of 3.7 on several occasions, the average production will be in the range of 6060 to 6120 kg in terms of RHA. This is close to the actual average of the data points (average SCC for the 24 observations is 3.72) and corresponds with the narrowest 95% confidence interval for the mean. In either direction away from the mean, the confidence interval widens. This is a standard aspect of linear regression. More confidence lies in assertions about the center of the data sets, so that the further from the average of the data the analyst wishes to extrapolate, the less certain he or she can be about the actual results. The other confidence interval is the 95% confidence given for any single observation. Note the terms used here: Previously the "average response of RHA to changes in SCC" was discussed, whereas here the confidence in a one-time estimation is discussed. Because of individual month-to-month variability in production, the ability to predict any *single* response is much cruder than the ability to predict an average response, and therefore, the interval for a single prediction is much wider.

Fig. 2-9 depicts a second screen capture from the Statistix program. This one performs an important aspect of linear regression analysis, an aspect testing for some of linear regression's assumptions, called *residual analysis*. In essence, this analysis predicts a new production level for each of the listed SCCs, takes the difference from the actual RHA and predicted RHA, and submits this difference to analysis.

The residual analysis created three new variables: the predicted RHA values using the regression equation (RHAFIT), a standardized residual or measure of how far each prediction is from the actual RHA value (STDRES), and a t-test *P*-value for whether a single value is an "outlier" (OUTLIER)—the smaller the *P*-value, the more likely the observation is an outlier. Graphically, a plot of residuals should appear as a random pattern of points; should an obvious pattern exist (i.e., all the middle range residuals were above the zero line and the points on either side occurred below the zero line), the assumption of linearity or equal variation between the dependent and independent variable does not hold. In such a case, then, the analysis needs to be interpreted very carefully, if not redone using transformed data. The graphic in Fig. 2-9 shows no indication of a telltale pattern; the assumptions of linearity and equal variation hold in this data set.

The data table in Fig. 2-9 has one row highlighted, the row for case 18 (corresponds to the data point from "Jul-01"

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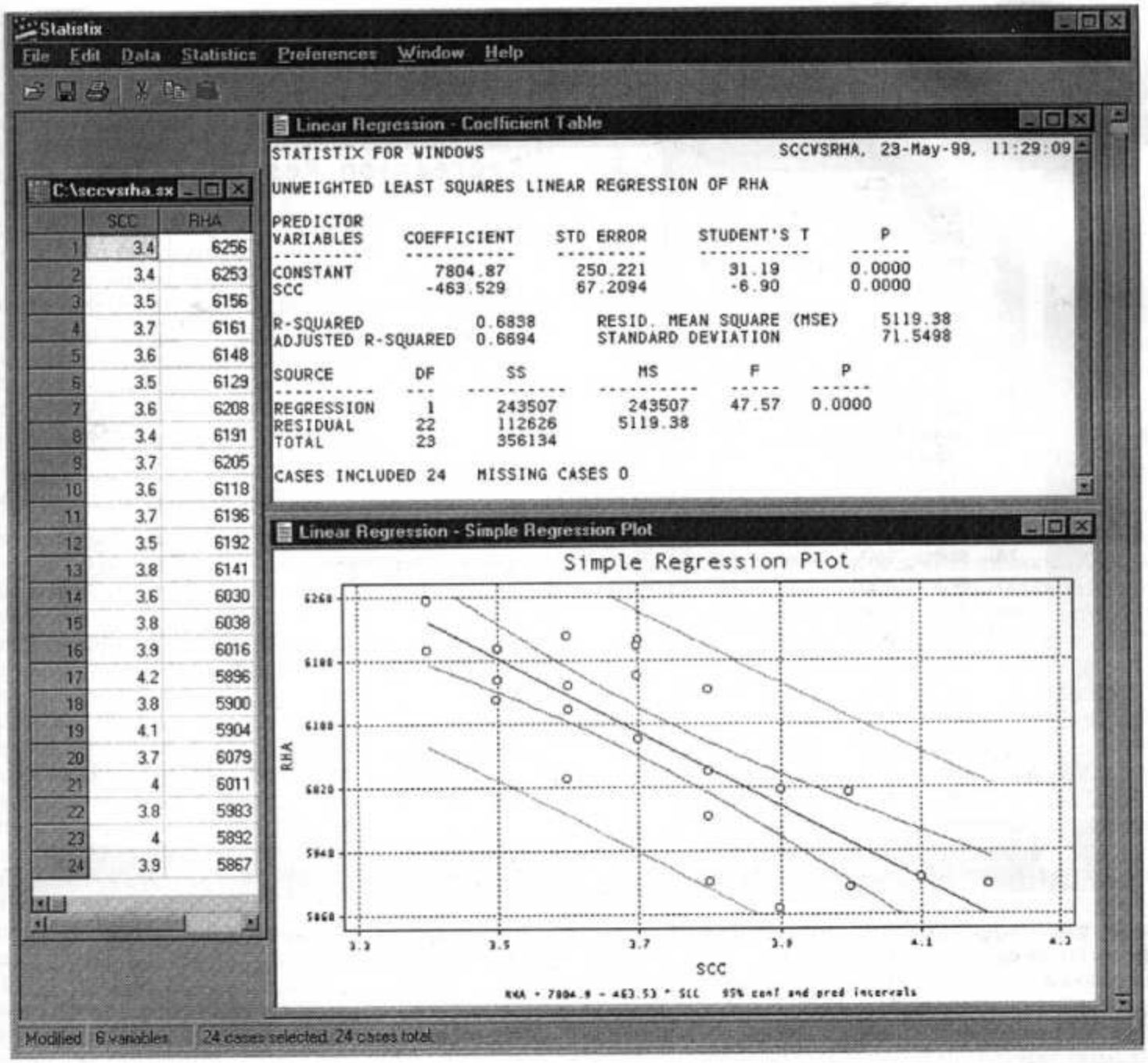

FIG. 2-8 Screen capture of typical output from a stand-alone statistics program (Statistix for Windows, Analytical Software) for the somatic cell code versus rolling herd average problem. The left window *(C:\sccvsrha.sx)* is the data listing. The top window *(Linear Regression - Coefficient Table)* is the linear regression report plus analysis of variance table. The bottom window *(Linear Regression - Simple Regression Plot)* displays a graphic of the linear regression and 95% confidence intervals for both the predicted (narrow band) and fitted (wider band) values.

in Spreadsheet Stats Worksheet 4). It has been highlighted because it is a potential outlier with a *P*-value of .04. Graphically, this is the lowest point in the chart, occurring midway between 6000 and 6080 on the x-axis and near −2.1 on the y-axis. The statistical test results in the "OUTLIER" column also identify cases 24 and 9 (the "Jan-02" and "Oct-00" data points) as potential outliers, with *P*-values of .06 and .10, respectively. Typically, the analyst would rerun the evaluation without one or more of these observations to see if the regression improved. Ideally, however, the analyst first would look for reasons why these data points should be excluded, other than their mathematical characteristics. For instance, if the "Jul-01" DHIA visit occurred the day after an equipment breakdown (i.e., the previous day's milking was 5 hours late), the analyst could feel there was support for removing that data point as an outlier. Likewise, if the "Jan-02" DHIA visit occurred during an ice storm, when the cows' exercise, feeding, and movement were drastically altered, the analyst might feel the data point were not representative of the herd's true abilities at that time. As a point in fact, for this herd, this is exactly what happened in both cases for the represented months.

Freeware Statistical Packages

Many organizations and groups offer "freeware" or "shareware" software, some of which can be quite sophisticated statistical packages. Perhaps the most widely used of the freeware packages is Epi Info from the Epidemiology Program Office of the Centers for Disease Control and Prevention (CDC) (Atlanta, Ga.). This package contains not only a set of statistical analysis modules covering a wide array of techniques, but a questionnaire developer, word-processing capabilities, a database module, a full on-line or printable manual, and potential connections to mapping and other surveillance software. While Epi Info is a registered trademark of the CDC, the actual software is available for free on the Internet at http://www.cdc.gov/epiinfo. Distributors include the CDC (Centers for Disease Control and Prevention, Division of Public Health Surveillance and Informatics,

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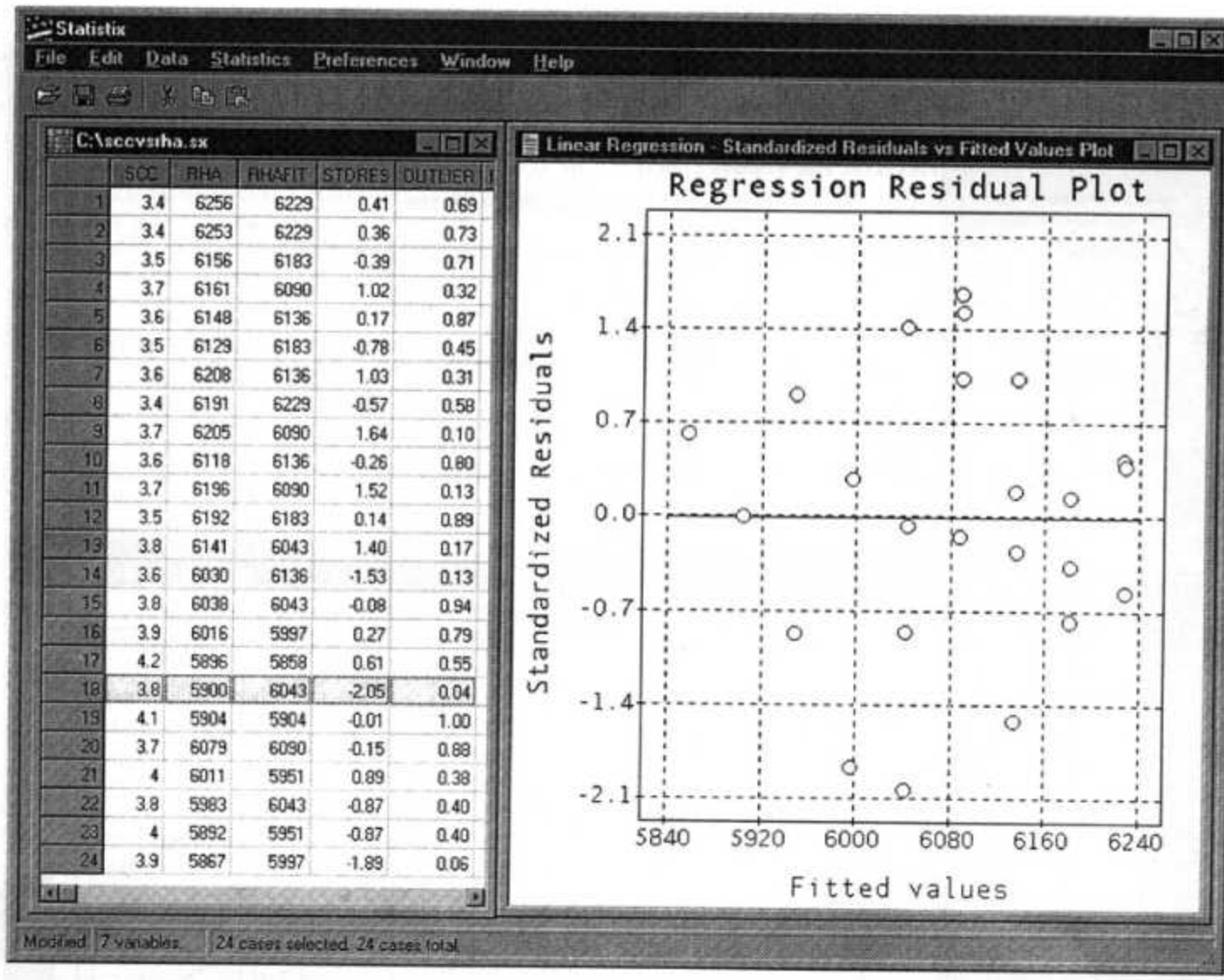

FIG. 2-9 Screen capture of typical output from a stand-alone statistics program (Statistix for Windows, Analytical Software) for the somatic cell code versus rolling herd average problem. The left window *(C:\sccvsrha.sx)* is the data listing, along with three new variables for residual analysis. Also shown is a graphical evaluation of residuals *(Linear Regression - Standardized Residuals vs Fitted Values Plot)*. The highlighted row (case 18) suggests that point is an outlier (value for column OUTLIER = 0.04) that may be overly influencing the regression. That point is the lowest point on the graphic.

Epidemiology Program Office, 4770 Buford Highway, MS K-74, Atlanta, GA 30341-3717), the World Health Organization (WHO), commercial vendors, translators, instructors in university and public health settings, and other public health professionals. A 1999 report (Harbage and Dean, 1999) documented that over 145,00 copies of the DOS version of Epi Info had been distributed, and its manual had been translated into 14 languages. Since 1994, the Internet has become a major means of propagation for this freeware, accounting for approximately two thirds of the copies known to be in existence.

As previously implied, Epi Info at time of writing is available in two versions: "Epi Info 6.04b upgrade to c" and "Epi Info 2000." The former is a DOS-based program that, in full, occupies approximately 15 Mb of disk space. The "upgrade to c" version contains a patch that corrects a problem in previous versions' Turbo Pascal compiler that produced a timing loop error on computers with processors faster than 200 MHz. In lay terms, that means that previous versions of the DOS program did not completely or reliably operate on anything but slower computers. For production medicine practitioners, the two major subprograms in Epi Info 6.04 are STATCALC and EPITABLE. These two modules allow the practitioner to enter data or summary information and quickly run a variety of statistical tests and statistical power calculations. The other version, Epi Info 2000, is a Microsoft Windows–based program that was first offered in mid-2000. In full, Epi Info 2000 occupies approximately 80 Mb of disk space. Its Windows format makes operating Epi Info 2000 more intuitive than Epi Info 6.04. However, the DOS version likely has more direct applicability to production medicine practitioners, because "2000" does away with EPITABLE and its ability to allow direct input of data without first generating an Epi Info data file. It still carries STATCALC (with its own ability to allow direct input of data without first generating an Epi Info data file), but the loss of the other module means that some of the quick utility of the DOS version is lost in the Windows version. However, Epi Info 2000 is easier to learn, is more adaptable, and likely will prove to be the dominant freeware statistical package for the coming decade or so.

DIAGNOSTIC TEST EVALUATION

Introduction

What is a Test?

A test is any device or procedure with the purpose of yielding information to help make decisions about a question or task at hand. In this wide view of what a test is, tests are performed anytime information is sought. Hence, whereas

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blood chemistries and bacterial cultures are recognized as tests, every assessment a clinician makes is, in truth, a test. For instance, when an animal's thorax is auscultated, the animal is tested with several criteria (sound quality, fluid lines, abnormal or missing sounds, etc.) that are believed to help differentiate normal from abnormal. When questions are asked regarding the history of an animal or herd, these details are used to rule in or out possible problems. Obviously, drawing blood for chemistries, hematology, or serologies are the same thing. In each situation, information is developed on how close the subject is to normality. The practical clinical value of a test, then, is based on its ability to provide information for making decisions. Not all tests are equal. Some have inherent biases in them. Some are not very repeatable. Not all tests are equal in differentiating normal from abnormal. A given test's weak points usually can be accounted for in analysis.

Reading Versus Interpreting Tests

Test strengths and weaknesses must be understood before moving from "reading test results" to "interpreting test results." Anybody can be given a sheet of test results, plus a sheet on where cutoff points are, and make decisions about the animals concerned. That is merely "reading test results" as if they were independent of everything else in the world. However, "interpreting test results" involves evaluating the test results given the underlying conditions—the likelihood of disease in the tested animals, the quality of the test itself—and using *all* the information at hand.

The next section looks at tests run in clinical situations. It starts with tests run on individual animals, before looking at tests applied over populations (the production veterinarian's main point of interest). The following points are covered:

1. Defining how all tests are uncertain
2. Looking into measures of test efficiency
3. Discussing how the disease environment (prevalence) affects test performance
4. Looking at how test efficiency affects performance when multiple tests are used on an individual and a single test is used on a population
5. Discussing the rationale in a screening-diagnostic testing strategy.

Sources of Uncertainty in Clinical Information

Variation in Data Quality

The general purpose of testing is to generate information that affects a future decision. The major way tests affect decisions is by allowing the decision maker to revise patients' probability of being diseased by separating a population into two or more groups, usually diseased and nondiseased. Four general characteristics of testing processes constitute the quality of information generated by tests: measurement errors, discrimination, accuracy, and precision.

Measurement Error. Instruments are not perfect, and the ability to manipulate the instruments varies. Difficult and exacting testing procedures are more prone to measurement errors, making the test less dependable. *Measurement errors* can be minimized by comparing a test's results against known standards. Laboratories do this by calibrating their instruments at regular intervals against known quantities. Many in-clinic tests now available are designed to be run in groups of three: the sample in question, a known positive, and a known negative. Such controls help minimize the chance of measurement error.

If a physical examination is actually a series of tests, how can measurement error be minimized? Clinicians recommend time and time again that findings on a suspect animal

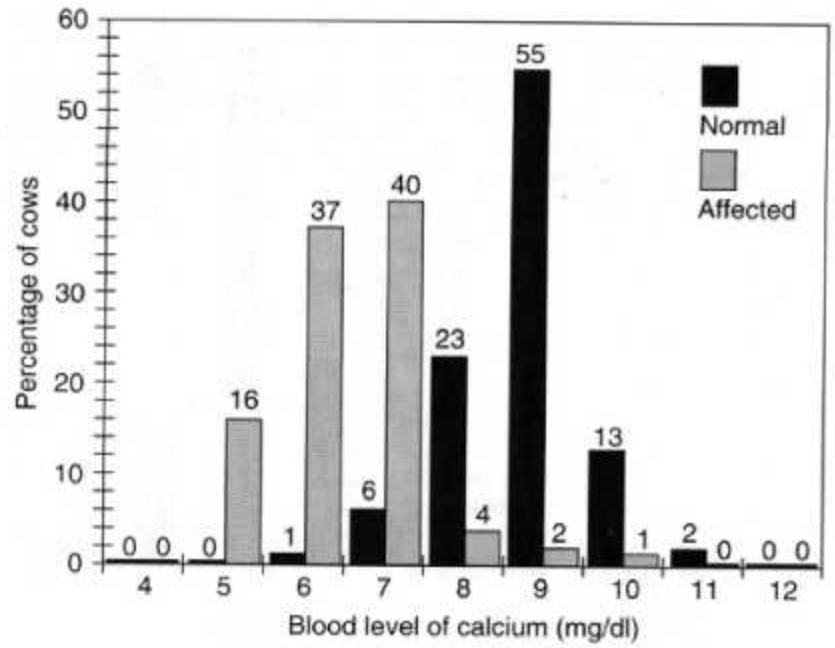

FIG. 2-10 Hypothetical distribution of cows from a study evaluating the relationship between blood calcium measures and clinical hypocalcemia. Some normal animals have low values of calcium, whereas some animals appearing affected with hypocalcemia have relatively high values. The degree of overlap indicates a test in which a perfect level of discrimination cannot be achieved.

be compared against those on a "normal" animal. For instance, when a clinician looks for radiographic abnormalities of a goat's tibiotarsal joint, he or she could take a few extra films of the opposite joint, using the animal as its own control. The same can be done in palpation of abdomens and joints, ocular examinations, auscultation, and any number of other common physical examination tests.

Discrimination. The term *discrimination* describes the ability of a *separator variable* (a threshold level of a blood chemistry, for example), exclusive of measurement errors, to separate one set of individuals from another. These separators are not exact. In Fig. 2-10, where should the line be drawn for blood calcium and milk fever? Regardless, a proportion of the individuals will be misclassified. For example, if the low end of normal is considered 8 mg/dl, 93% of both groups will be identified correctly. However, at the same time, approximately 7% of the affected animals will be incorrectly identified as also being "normal" (false-negative test result). If a higher limit is considered, such as 9 or 10 mg/dl, a higher proportion of truly hypocalcemic animals (98% and 99%, respectively) will be identified. However, increasing percentages of "normal" animals would be identified as potential hypocalcemia cases (false-positive results of >30% and 85%, respectively). There is a wide amount of individual variation; hence perfect discrimination between "normal" and "abnormal" cannot be achieved. By knowing this limit, often the choice of where to draw the line becomes one of practicality or economics, not physiology.

Accuracy. A test's *accuracy* pertains to the tendency of test measures to center around the actual, or true, value of that measure. Accuracy is difficult to ascertain, since it requires some standard measure against which to compare. Most errors in accuracy are systematic errors (for example, a blood glucose testing instrument is always 10 mg high) that lend *bias* to a test. A bias is simply a nonrandom directed error or a variation that is primarily in one direction, such as a thermometer that always reads either too high or too low. Inaccurate tests tend to shift a measure's distribution (Fig. 2-11), and therefore the measure's mean, to the right or left of the actual values. Inaccuracy does not,

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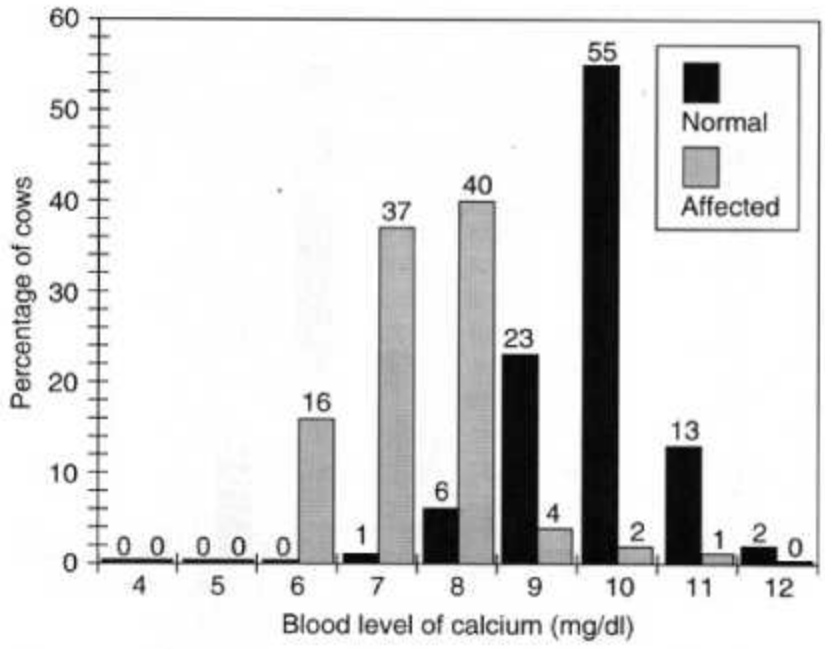

FIG. 2-11 Hypothetical distribution of cows from a quality control evaluation of a blood calcium–measuring technique. The two distributions, compared with those in Fig. 2-10, show a systematic upward bias of approximately 1 mg/dl. This does not change the test's ability to discriminate between the "normal" and "affected" populations; the difference between the central values is similar to that from the previous figure, and the dispersion stays the same.

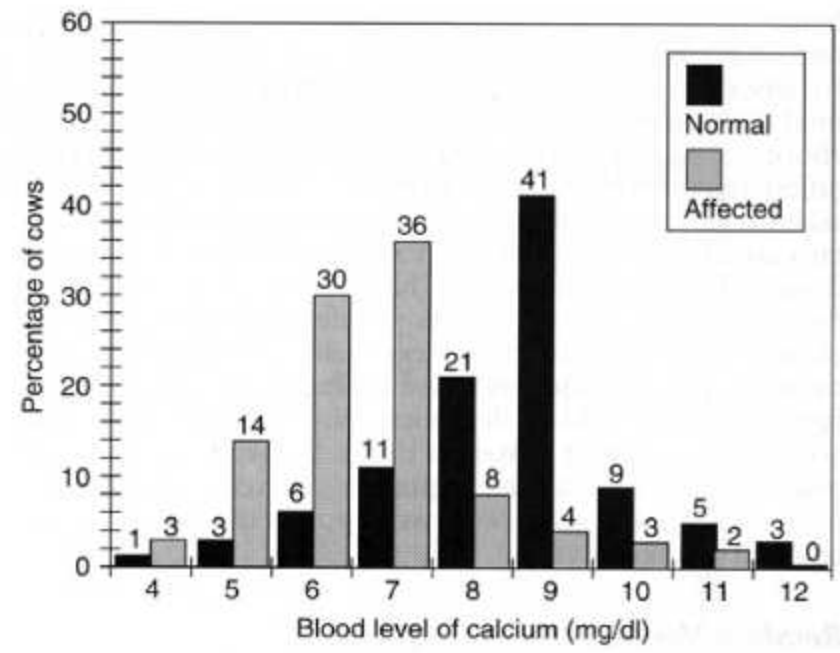

FIG. 2-12 Hypothetical distribution of cows from a quality control evaluation of a blood calcium–measuring technique. Compared with the distributions in Fig. 2-10, these distributions show a random bias. The centers of the populations are approximately the same; however, both distributions are flatter and wider than those in Fig. 2-10. This causes their amount of overlap to increase, decreasing the test's ability to discriminate.

however, affect the spread, or variance, of the distribution; if this instrument is known to measure 1 mg/dl too high, and the bottom end of normal is adjusted to an indicated 9 mg/dl, 93% of both groups again would be correctly identified. Hence, inaccuracy, in and of itself, does not change a test's discriminatory ability. When facing a bias, repeating the test does not improve the results. Improved calibration and changing tests are the only means to alter test accuracy.

Precision. The *precision* of a test, also known as *test reliability*, refers to the level of random variations in test results. Imprecision tends to cause a distribution of test results to have the same mean as the reference test's values but with a larger variance. Graphically, imprecision causes a series of test results to form a low, wide distribution curve compared with the reference distribution curve (Fig. 2-12). Imprecision in tests blurs discrimination lines because it increases the range of values over which the analyst is forced to name a category of results as being normal or abnormal. For instance, in this case, if 8 mg/dl is kept as the low end of normal, only 79% of the normal population (yielding a 21% false-positive test proportion) and 83% of the affected population (resulting in a 17% false-negative test proportion) would be identified correctly. Since the variation in imprecise tests is random, repetition of imprecise tests tends to give average results that approximate the true value of the index and therefore improve the confidence one has in decisions based on that information.

Measures of Test Efficiency in Clinical Decision Making

Definitions of "True" and "False" Negatives and Positives

Tests can be evaluated in terms of their efficiency at discriminating among groups of individuals. A dichotomous test, defined as giving results that register either "positive" or "negative" for some quality, can be used as an example. While tests that generate continuous results (i.e., liver enzyme levels) can be used, dichotomous results allow "either-or" clinical decisions to be made (either an animal is or is not treated). Hence, tests are often measured in terms of their dichotomous results as in a 2 × 2 contingency table. Fig. 2-13 shows a contingency table on the left comparing a hypothetical test (indicated as T+ and T−) with a state of nature (DZ+ and DZ−), and a table on the right explaining the terms used in describing test efficiency. From the contingency table data, information can be generated on some valuable efficiency index ratios (ratios that help determine whether a test is worthwhile). The "significance" of a ratio is the disease-relative probability value the ratio represents. For example, the sensitivity of a test is the probability of a test being positive, given the presence of disease. (The P(T+|DZ+) is an algebraic expression of this statement, where the "|" is read as the word "given.")

Sensitivity (SE) of a Test. The SE of a test is a measure of that test's ability to identify true positives, given that the tested group is truly positive. In a 2 × 2 table (as in Fig. 2-13), the SE is given by the cell signifying the positive agreements between the test and a gold standard divided by the marginal total of truly diseased animals. The higher the *sensitivity*, the better the test at pulling truly diseased animals from a group.

Specificity (SP) of a Test. A test's SP is a measure of that test's ability to distinguish true negatives, given that the tested group is truly negative; the cell signifying the negative agreements is divided by the marginal total of truly negative animals. The higher a test's *specificity*, the better the test at identifying nondiseased animals and leaving them be.

SE and SP are of limited usefulness by themselves because they each are calculated using only one side of the 2 3 2 table (i.e., either the state of nature diseased or the state of nature nondiseased side). The values desired (i.e., the likelihood that an animal a test labels "positive" is truly diseased) need to be calculated using both sides of the table (i.e., either the "total number of test positives" or "total number of test negatives"). This "vertical" alignment of SE and SP also means that neither is necessarily affected by prevalence of

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1. Basic abbreviations

A. ***DZ+/– (state of nature)***	*Column depicts either diseased (DZ+) or nondiseased (DZ–) animals.*
B. ***T+/– (test results)***	*Row depicts either positive (T+) or negative (T–) testing results.*
C. ***TP (true positives)***	*Both Test and State of Nature indicate positive results.*
D. ***FP (false positives)***	*Test is positive, but State of Nature is disease negative.*
E. ***FN (false negatives)***	*Test indicates negative, State of Nature is positive.*
F. ***TN (true negatives)***	*Both Test and State of Nature indicate negative.*

2. Contingency table example and explanation of TP, FP, TN, FN

Assume you tested a 640-sow barn for some disease. 77 animals tested positive, and 563 tested negative. Unknown to you, 17 test positive animals are false positives, and 4 test negative animals are false negatives. In actuality, 64 animals were diseased and 576 were nondiseased. The testing program results could be displayed as the following:

TEST RESULTS

	DZ+	DZ–	
T+	60	17	77
T–	4	559	563
	64	576	640

EXPLANATION

	DZ+	DZ–	
T+	TP	FP	TP+FP
T–	FN	TN	FN+TN
	TP+FN	FP+TN	TOTAL

3. Definitions of efficiency index ratios

INDEX RATIOS	CALCULATION	EXAMPLE RESULTS		SIGNIFICANCE
A. PREVALENCE	(TP+FN)/TOTAL	64/640	= 10%	P(DZ)
B. SENSITIVITY	TP/ (TP+FN)	60/64	= 0.94	P(T+|DZ+)
C. SPECIFICITY	TN/ (FP+TN)	559/576	= 0.97	P(T–|DZ–)
D. FALSE POSITIVE RATE	FP/ (FP+TN)	17/576	= 0.03	P(T+|DZ–)
E. FALSE NEGATIVE RATE	FN/ (TP+FN)	4/64	= 0.06	P(T–|DZ+)
F. PREDICTIVE VALUE POSITIVE TEST	TP/ (TP+FP)	60/77	= 78%	P(DZ+|T+)
G. PREDICTIVE VALUE NEGATIVE TEST	TN/ (FN+TN)	559/563	= 99%	P(DZ–|T–)

FIG. 2-13 Basic setup of a diagnostic test evaluation table, using the contingency table convention to display test results. Index significance is read as the "probability of (event)." For instance, *P*(T+|DZ+) is read as "probability of an animal testing positive, given that it has the disease."

disease, as long as the prevalence does not affect the animals' display of characteristics used for testing. For instance, in the case in a neonatal gastrointestinal disease situation, often the higher the prevalence of the pathogen, the more it gets amplified as it passes from case to case, making the signs and symptoms more apparent as prevalence rises. In these types of situations, then, SE and SP of a test can change with prevalence. These cases are, however, the exception to the rule; SE and SP, being calculated using only the diseased or the nondiseased subgroups, are largely indifferent to prevalence.

The aforementioned is certainly not true for the *predictive values*. The "horizontal" alignment of the values of interest thus means that they *are* affected by prevalence. In general, then, the nature of a test (SE and SP) is not a function of disease prevalence, but its performance (predictive value of a positive test, predictive value of a positive test) is.

Prior Probabilities and Posterior Probabilities. In most situations the prevalence of a disease is called the *prior probability* of that disease occurring. This term is used because it is the probability of the disease occurring *prior* to any investigation or test being performed. As stated before, the purpose of a clinical test is to revise probabilities of disease. This is what the predictive value of a positive test (PVPT) and the predictive value of a negative test (PVNT) accomplish. The PVPT and PVNT of a test are *posterior probabilities* of disease. They are posterior probabilities because they come *after*, or posterior to, a test. They represent the revised probability of an animal's being diseased (or nondiseased). In general, the lower the prevalence, the worse the PVPTs and the better the PVNTs. The opposite is true for higher prevalences; PVPT improves and PVNT worsens. Most tests have their highest combined PVPT and PVNT somewhere in the mid-ranges of disease prevalence.

PVPT and PVNT are also asymmetrically affected by SE and SP. Fig. 2-14 shows predictive values over a range of prevalences from 0% to 100%, with SE held constant at 95% and three separate SPs (80%, 90%, 99%). Note the relationship of PVPT and PVNT with prevalence as described previously. Also note how PVPT is affected to a greater degree by changes in SP than is PVNT. Fig. 2-15 shows a similar graph, except that this time SP is held constant at 95% and SE varies from 80%, to 90%, to 99%. PVNT is evidently the more affected posterior probability when SE is the characteristic that changes. One way to remember this pattern is to think of SE and SP as elastic bands that pull the PV calculations toward the upper-right or upper-left corners of such a graph. As SE rises, PVNT is pulled to the upper-right corner. As SP rises, PVPT is pulled toward the upper-left corner.

Whereas, at first, it may seem counterintuitive that the test characteristic that determines a test's ability to correctly identify *diseased* animals (sensitivity) should most affect the posterior probability that registers confidence in *test negatives* (PVNT), the relationship makes sense with a moment's reflection. If, for instance, a test had a poor sensitivity, by definition it would incorrectly identify a number of diseased

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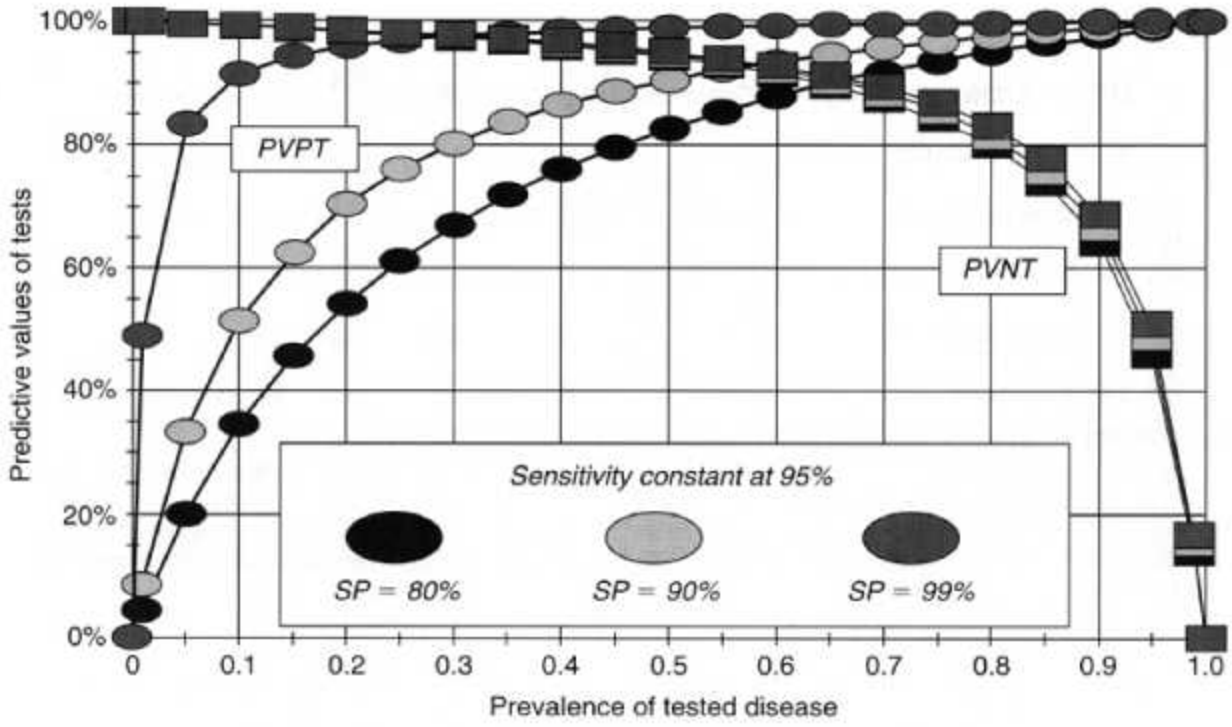

FIG. 2-14 Depiction of the effect of changing prevalence and specificity *(SP)* on the predictive values of a test. As prevalence rises, predictive value of a positive test *(PVPT)* rises and predictive value of a negative test *(PVNT)* drops, both in a curvilinear fashion. PVPT is apparently much more affected by changes in specificity than is PVNT.

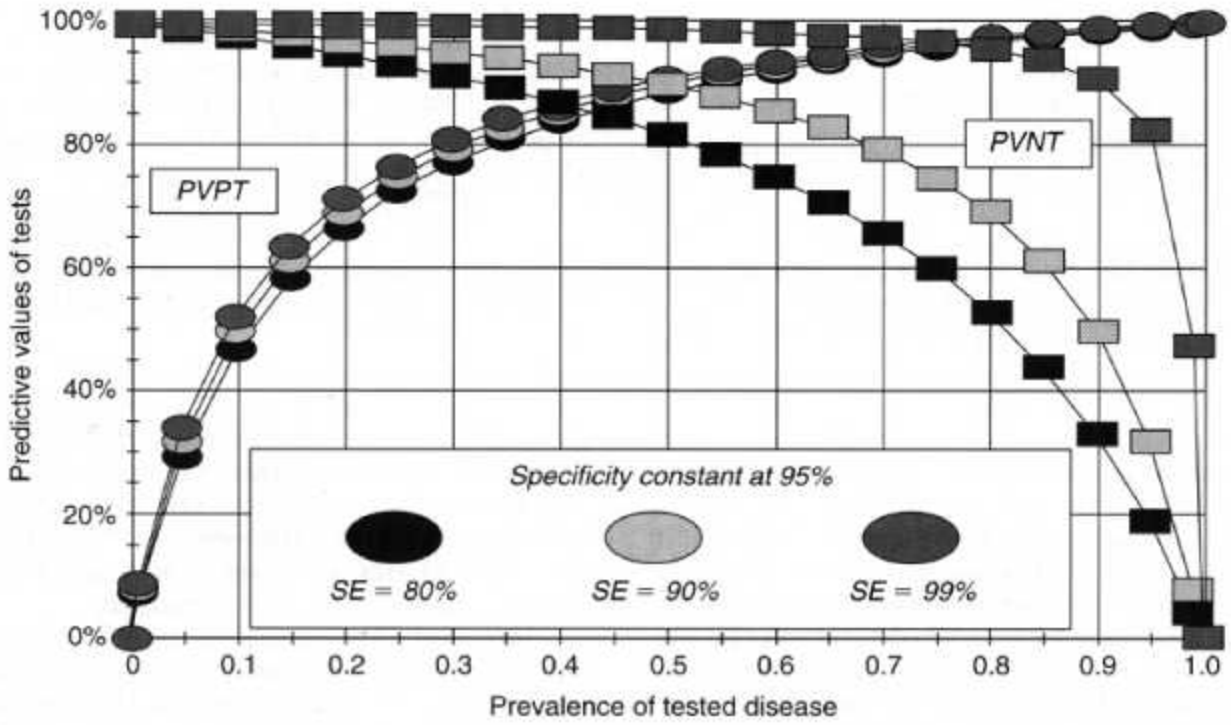

FIG. 2-15 Depiction of the effect of changing prevalence and sensitivity *(SE)* on the predictive values of a test. As prevalence rises, predictive value of a positive test *(PVPT)* rises and predictive value of a negative test *(PVNT)* drops, both in a curvilinear fashion. PVNT is apparently much more affected by changes in sensitivity than is PVPT.

animals as nondiseased—the false negative rate (FNR) will rise. Since the PVNT is calculated as the number of true negatives/(true negatives + false negatives), an increase in the FNR *lowers* PVNT (see Fig. 2-13 for review). For PVPT, the calculation is the number of true positives/(true positives + false positives)—as true positives increase, they cause an increase in *both* the numerator and denominator, dampening the change in the overall value of the proportion. The converse is true when specificity is the value that changes, making PVPT the most affected posterior probability.

Likelihood Ratios and Figuring Out the "Gray" Zones in Clinical Tests

Unfortunately, most tests are not perfectly discriminating; they each yield some proportion of false positives (FPs) and false negatives (FNs). The original hypothetical blood calcium data from Fig. 2-10 shows this. It is apparent that, within reason, any animal testing at or above 11 mg/dl can be considered "negative" (i.e., normal), because with this data set no affected animals achieved this high a blood calcium level. It is just as apparent that those testing below 6

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mg/dl can be considered "positive" (i.e., hypocalcemic). So at least an upper and lower boundary can be established on classification. The animals testing above 6 mg/dl and below 11 mg/dl, however, are another story; they cannot automatically be assumed to be either "negative" or "positive" without running the risk of misclassification. There is a way to rank these outcomes and give some probabilistic means of selecting any given animal's most likely class. It invokes what are called *likelihood ratios*.

A likelihood ratio (LR) is simply the ratio formed by dividing the proportion of the diseased population testing at some predetermined level by the proportion of the nondiseased population testing at the same level. Suppose that, using the data in Fig. 2-10, the analyst determines the LR for a blood calcium level of 9 mg/dl. In this example, 85% (55+23+6+1 = 85) of the unaffected group tested at or below this level, whereas 99% of the affected group (2+4+40+37+16 = 99) tested at this same level. The LR for 9 mg/dl would be 99/85 = 1.16. Thus affected animals are about 1.16 times as likely as unaffected animals to test at or below this level. The LR, then, is the odds that 9 mg/dl of blood calcium would be expected in an affected cow versus an unaffected cow. As another example, the LR can be developed for establishing a cutoff point for a blood calcium level of 6 mg/dl:

Proportion of affected cows with blood calcium ≤6 mg/dl
$= 37 + 16 + 0 + 0 = 53$

Proportion of unaffected cows with blood calcium ≤6 mg/dl
$= 1 + 0 + 0 + 0 = 1$

Likelihood ratio for 6 mg/dl $= 53/1 = 53$

This means that blood calcium results at or below 6 mg/dl are *53 times more likely* to come from cows affected with hypocalcemia than from cows not clinically hypocalcemic. The full 2 × 2 contingency table for a finding of 6 mg/dl would appear as follows (refer to Fig. 2-10 for data):

	Hypocalcemic	Normal	Total
Test positive (blood calcium ≤6 mg/dl)	53	1	54
Test negative (blood calcium >6 mg/dl)	47	99	146
Total	100	100	200

The LR, then, is actually the proportion formed from SE/FP, or SE/(1–SP). In this case, this would be (53/100)/(1/100) = 53/1 = 53 (refer to Fig. 2-13 for review as needed). Indeed, this is another means of calculating an LR. In this 2 × 2 table calculation, predictive values should not be generated, since the underlying proportion is arbitrarily set at 50% because proportions from two separate groups were used. However, in a herd in which hypocalcemia occurs in half the cows, this table *can* be used for predictive values. I pity the reader, and the reader's client, if this is actually the case.

Given the previous information, LRs can be calculated for all levels of blood calcium outcomes. Table 2-3 does just this. Inspection of this table should reveal an intuitive trend in LRs. As the cutoff value for the test is set at an ever lower level of blood calcium, the likelihood of achieving such an outcome from a hypocalcemic animal becomes much more probable. This fits with the knowledge that hypocalcemic animals have lower levels of blood calcium. The LR quantifies that relationship. The next part of this discussion shows how to use this new information in interpreting test results.

Using Likelihood Ratios to Improve Diagnostic Test Evaluation. LRs are used to develop posterior probabilities of an animal's being normal or abnormal. The method is simple; it often can be accomplished without paper. The logic behind it follows that the probability (or odds) of an animal's being diseased after test results are obtained is derived from the prior probability of the animal's being diseased, multiplied by the test's likelihood ratio. The equation form follows:

$$\text{Posterior odds of disease} = \text{Prior odds of disease} \times \text{Likelihood ratio}$$

This is written formally as follows:

$$\frac{P(DZ+|T+)}{P(DZ-|T+)} = \frac{P(DZ+)}{P(DZ-)} \times \frac{P(T+|DZ+)}{P(T+|DZ-)}$$

In terms of Fig. 2-13, this is equivalent to the following:

$$\frac{PVPT}{1 - PVPT} = \frac{PREV}{1 - PREV} \times \frac{Se}{FPR}$$

in which FPR is the false positive rate.

The prior odds of an animal's having the disease in question is formed by the following equation:

$$\frac{\text{Disease prevalence}}{1 - \text{prevalence}}$$

This is the "no other information available" position to take—if nothing else is known about the animal, its probability of disease is the overall population prevalence. This is not always the case, for an animal may be considered more likely than the underlying prevalence would suggest to have a disease after a close physical examination. For instance, in a certain dairy herd periparturient hypocalcemia may occur at a proportion of 1 case per 20 calvings (i.e., 5%). However, if a cow is examined that is 48 hours postpartum, has no signs of trauma or septicemia, is unable to rise, has cold ears, and appears depressed, she would seem to be at higher risk of being hypocalcemic than a random 5% selection would present. In essence, the physical examination changed the prior probability of 5% to a higher posterior probability—the physical examination is a true test.

If a test is to have the ability to revise probability of disease being present (the definition of test value), the *LR* must be different from 1.0. For the test in Fig. 2-13 the likelihood ratio is 0.94/0.03, or 31.33, indicating this is a useful test in revising disease probabilities. For the current example, Table 2-3 suggests that the blood calcium test is useful in differentiating diseased cows from nondiseased cows until the cutoff point is set at 9 mg/dl or higher—at those levels the LR for the test approximates 1.0 and is not informative.

Using Likelihood Ratios in Establishing a Single Cutoff Threshold for Normal and Abnormal. The simplest application of LRs is to help establish a cut-point for decision making. On one side of the cut-point the animal is classified normal, and on the other side it is classified as abnormal. Suppose the practitioner examines a cow and believes, given the presented signs and history, that it has a 33% chance of being hypocalcemic. Assume also that this test being discussed is a quick cow-side test. The result is that the cow in question has a blood calcium level of 7 mg/dl, just a bit below normal. How much more likely is the cow to be hypocalcemic and therefore a good candidate for calcium therapy? The LR and previous mathematical expression can be used to calculate it:

Posterior odds of disease = Prior odds of disease × Likelihood ratio
$= 33/67 \times 13.3$
$= 0.5 \times 13.3$
$= 6.7$

So, after the test is run, the posterior odds estimate for the cow's being hypocalcemic is 6.7:1. This can be converted to a probability. Refer to the discussion of converting ratios to

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TABLE 2-3

*Derivation of Likelihood Ratios for Different Cut-off Values**

Blood Calcium (mg/dl)	Hypo-Calcemic Cows	Normal Cows	Calculation of Likelihood Ratios	Likeli-hood Ratio
4	0	0	(0)/(0) = 0/0	na (big)†
5	16	0	(0+16)/(0+0) = 16/0	na (big)
6	37	1	(0+16+37)/(0+0+1) = 53/1	53.00
7	40	6	(0+16+37+40)/(0+0+1+6) = 93/7	13.29
8	4	23	(0+16+37+40+4)/(0+0+1+6+23) = 97/30	3.23
9	2	55	(0+16+37+40+4+2)/(0+0+1+6+23+55) = 99/85	1.16
10	1	13	(0+16+37+40+4+2+1)/(0+0+1+6+23+55+13) = 100/98	1.02
11	0	2	(0+16+37+40+4+2+1+0)/(0+0+1+6+23+55+13+2) = 100/100	1.00
12	0	0	(0+16+37+40+4+2+1+0+0)/(0+0+1+6+23+55+13+2+0) = 100/100	1.00

*Table differentiates between affected and nonaffected animals for the hypothetical testing for blood calcium demonstrated in Fig. 2-10. The likelihood ratio expresses the odds that the test level would be expected in a hypocalcemic cow as opposed to a normal cow. Hence, a blood calcium value of 7 mg/dl is over 13 times more likely to come from a hypocalcemic cow than from a normal cow.
†Result of *na (big)* means that the arithmetic operation cannot be performed (cannot divide by zero); however, the analyst should be aware that the LR for this test level would be much higher (i.e., "bigger") than any value derived lower in the table.

proportions: Take the numerator and divide by the sum of the numerator and denominator (for 6.7:1 this comes to 6.7/[6.7 + 1] = 6.7/7.7 = 87%). Before the test, then, the probability that the cow was diseased was thought to be 33% in round figures. After the test is run, even though the results would often be considered as "borderline low," the confidence that the cow truly has the disease is now nearly 90%. Even at this moderately low level of blood calcium, a much higher proportion of hypocalcemic cows show such a result as opposed to normal cows. In other words, this worked because the test has, at 7 mg/dl, an LR much higher than 1.0.

What if the test result had been 8 mg/dl instead of 7 mg/dl? Insert the new LR for 8 mg/dl (3.2; see Table 2-3) into the previous expression:

$$= 0.5 \times 3.2 = 1.6$$

This yields a probability of the cow's being diseased of 1.6/2.6 = 62%. A relatively small move in blood calcium levels has lowered the confidence that the cow is hypocalcemic from nearly 90% to about 60% because the ratio of animals with and without hypocalcemia having such a blood level is fairly close. With this disease, the practitioner is most likely to go ahead and treat because the negative potential of treating the cow with calcium is low if she is *not* hypocalcemic. However, if the decision were not about intravenous calcium treatment, but about removing a teat or cauterizing a quarter, the practitioner might not be willing to proceed with treatment if there is a 40% chance the diagnosis is wrong.

Which is the better cutoff? 7? 8? Table 2-3 shows that over 90% of the affected animals fall in the ≤7 mg/dl range, and over 90% of the unaffected group fall in the ≥8 mg/dl range. Since percentages are being used here, these are equivalent to SE and SP. With a cutoff of 7 mg/dl, an SE of 93% and an SP of 93% result. Moving up to 8 mg/dl captures a few more unusual cases, but it also increases the FPs so that SE comes to 97% but SP drops to 70%. The best, overall test performance occurs with a cutoff of ≤7 mg/dl; animals falling in this range are over 13 times more likely to be hypocalcemic than not.

Using Likelihood Ratios to Help Make Decisions About Individual Animals by Dispensing With Either/Or Cut-Points. The previous argument, in the end, was decided by relative changes in SE and SP—the LR only clarified the magnitude of effect of changing the cut-point. The LR can be used in a much more powerful way, however, and that is to dispense with single cut-point decisions and move to a more substantial use of diagnostic tests that give quantitative results. The process involves establishing a true low-end cut-point, a true high-end cut-point, and setting up a range of LRs for the middle group. This process also uses SE, SP, and LRs to make the point.

Sackett et al (1991) use two terms that help in this activity: "SnNout" and "SpPin." *SnNout* is an acronym that represents the method for establishing a "rule-in" target level for any test: *"...if a sign, symptom, or other diagnostic test has a sufficiently high Sensitivity, a Negative result rules out the target disorder..."* Hence, most tests have a threshold at which test SE is so high that great confidence is gained in negative results and a disease is ruled out. *SpPin* addresses the opposite situation: *"...if a sign, symptom, or other diagnostic test has a sufficiently high Specificity, a Positive result rules in the target disorder...."* Hence, for most continuous outcome tests, a threshold also exists at which test SP is so high that any positive finding carries great predictive weight. These two rules can be invoked with the blood calcium data in Table 2-3.

If the practitioner is willing to miss 1% of each type of animal (affected and unaffected), the SE level for SnNout and the SP level for SpPin is 99% for each. Examination of Table 2-3 shows that an upper cut-point of ≥10 mg/dl captures 99% of the affected population (i.e., SE = 99%). Likewise, a lower cut-point of ≤6 mg/dl releases 99% of the unaffected population (i.e., SP = 99%). So any animal testing over 9 mg/dl is considered "normal" automatically by invoking the SnNout rule, and any animal testing <7 mg/dl is considered hypocalcemic automatically by invoking the SpPin rule. That only leaves animals that

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could test between these values: those at either 7, 8, or 9 mg/dl.

The difference in the approach here, as opposed to the previous section on establishing a single cut-point, is that the focus is no longer on estimating the population differences on either side of these single values, but how the two groups differ at each value. This is easily found from Fig. 2-10:

LR for animals at 7 mg/dl
= % affecteds/% unaffecteds = 40/6 = 6.67

LR for animals at 8 mg/dl
= 4/23 = 0.17

LR for animals at 9 mg/dl
= 2/55 = 0.04

Note the difference in what is being evaluating here, compared with the earlier examples. Any animal testing out at 7 mg/dl for blood calcium is 6.67 times more likely to be affected than not, and any animal testing out at 8 mg/dl is 17% as likely to be affected than not (i.e., odds are approximately 5/1 the animal is unaffected). Odds are better than 20/1 that an animal testing at 9 mg/dl is unaffected. The entire population is not being captured up to those levels, just the animals at those levels.

So how is the information previously mentioned clinically? Assume there is another down cow. Because of other clinical signs, the practitioner thinks the cow is only 10% likely to be clinically hypocalcemic. The hypothetical cow-side test is run. The rules of action are as follows:

1. If the test result is 10 mg/dl or higher, the cow is considered *not* affected with hypocalcemia and *not* treated
2. If the test result is 6 mg/dl or less, the cow *is* affected with hypocalcemia and *is* treated
3. If the test result is in between, the individual level LRs are used to calculate a posterior probability of disease and determine treatment

Blood test result	Calculation of odds of disease in example cow	Posttest probability
7 mg/dl	0.10 × 6.67 = 0.667:1	= 40.0%
8 mg/dl	0.10 × 0.17 = 0.017:1	= 1.7%
9 mg/dl	0.10 × 0.04 = 0.004:1	= 0.4%

If the prior probability for the cow to be hypocalcemic had been 67%, instead of 10%, the final posttest probabilities of hypocalcemia would have been approximately 82% for 7 mg/dl, 10% for 8 mg/dl, and 2% for 9 mg/dl. Had the prior probability for hypocalcemia been 90%, the posttest probabilities for 7, 8, and 9 mg/dl would fall out as approximately 86%, 14%, and 3%, respectively. The higher the initial estimate of the likelihood of the cow's being diseased, the more likely she is to be diseased after a test is run. Fig. 2-16 displays a histogram of the distributions from both affected and unaffected animals, marks the earlier rule-in and rule-out ranges, and shows the individual test level LRs.

What Does All This Individual-Animal Diagnostic Stuff Have to Do with Production Medicine? This "diagnostic stuff" defines a clear and repeatable means of establishing the rules regarding initiating treatment for any disease that is tested with a quantitative scale (as opposed to tests that yield qualitative "yes-no" results). A major role for production medicine veterinarians is in training their clients to use and operate treatment protocols. In modern animal agriculture, the veterinarian is less frequently being called on to treat animals; the client does this work more and more. The veterinarian accepts the responsibility for designing credible treatment protocols for the client to use. Evaluating diseases and tests for those diseases gives the consulting veterinarian a new tool in designing protocols to make the client's work efficient, to minimize wasted time and money in unneeded testing or inappropriate treatment, and to deliver better care to the animals involved. It also gives the consulting veterinarian a framework from which to evaluate new tests or diagnostic procedures.

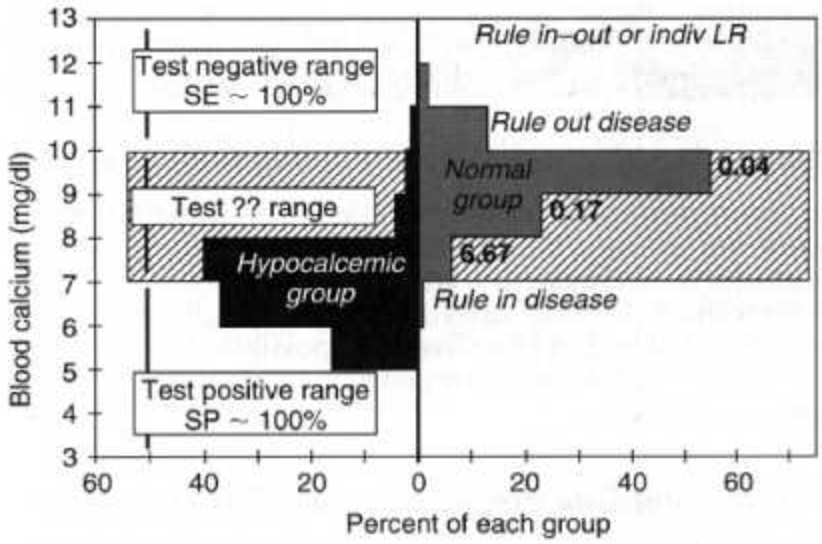

FIG. 2-16 Depiction of the interpretation and decision process regarding test outcomes for the hypothetical blood calcium example. The solid area histograms *(Hypocalcemic group* and *Normal group)* represent the populations listed in Table 2-3. Using the SnNout and SpPin rules (see text for explanation of abbreviations), the test positive and test negative ranges were established. The striped area demarcates intermediate test results (7, 8, and 9 mg/dl) that require use of the individual test likelihood ratios (LR) (ratio of the proportion of diseased animals testing at this level divided by the same proportion from the nondiseased group) and estimates of prior probability of disease to determine how to classify those animals. *SE,* Sensitivity; *SP,* specificity.

In the earlier case, suppose a veterinarian is designing the diagnostic and treatment protocol for a dairy to deal with hypocalcemic cows and this hypothetical cow-side blood calcium test. The veterinarian could design a process as detailed previously, or he or she might wish to depend more on the test, as opposed to the client's ability to create pretest probabilities. For instance, suppose the client's physical examination skills, and hence ability to estimate the probability of an animal's being diseased, were poor. After inspection of the effects that changes in pretest probabilities have on test outcome, the practitioner might decide to increase the rule-in and rule-out ranges because at a 90% prior probability of disease, a finding of 8 mg/dl results in a posttest probability of disease of 14%. This is not a high enough probability for most people to opt for treatment. If so, this means that the rule-out range is actually from 8 mg/dl on up and that only animals testing at 7 mg/dl are in question. This allows a diagnosis and treatment protocol to be designed based on the skills of the client, the type and nature of the disease, and the quality of testing methods. Should the client be better at physical examination, or should the client have more experience at working with the disease, the diagnosis and treatment protocol could be designed to allow for more client latitude (i.e., depending on the client's diagnostic skills) in classifying animals for treatment.

Should a new testing regime be made available, the veterinarian can apply the new test's capabilities to the same framework and determine if the new test will be an improvement on the client's operation by comparing its ease of use and ability to discriminate against the current process. In either case, whether designing treatment protocols or

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evaluating new tests, the veterinarian can use LRs, SpPin, and SnNout in building and adjusting individual protocols for each client in a repeatable, defensible manner.

Testing Populations Versus Testing Individuals

In production medicine the group is typically the unit of interest. For instance, batteries of tests are often done when an outbreak is investigated or when an import-export function is performed. In these cases multiple independent tests affect the likelihood of FPs. Given this possibility, the way tests are viewed needs to be revamped when they are applied over large populations.

Determining True Prevalence from Test Outcomes

Working with imperfect tests often means incorrectly estimating true prevalence, associating it with "apparent prevalence." To understand how to derive true prevalence is a useful skill in working with disease programs and less-than-perfect tests. For example, the practitioner may take a statistical sample of pigs on a farm, test them for pseudorabies, and then attempt to come to a conclusion about the herd's overall pseudorabies status. In cattle, the tuberculosis and brucellosis programs have similar processes. Practitioners are not always good at interpreting these test results in light of the tests' qualities. The problem, simply put, is the confusion about the difference between *apparent prevalence* versus *true prevalence*. For example, suppose a beef client, after having his 104 cow herd tested for brucellosis (using complement fixation as the only test), is informed that 41 animals tested positive (39% apparent prevalence). Is that the true level of disease in this herd? The true prevalence must be deduced. This is easily calculated by the following formula:

$$\text{TPv} = \frac{\text{APv} + (\text{Sp} - 1)}{\text{Sp} + (\text{Se} - 1)}$$

in which TPv is true prevalence and APv is apparent prevalence. If the Se and Sp of the complement fixation test are known, the true prevalence of the disease can be calculated. Huber and Nicoletti (1986) found the CF test's sensitivity to be 0.90 and its specificity to be 0.58. The APv has been determined already to be 39%. Plugging this into the equation gives the following:

$$\text{TPv} = \frac{0.39 + (0.58 - 1)}{0.58 + (0.90 - 1)} = \frac{-0.03}{0.48} = -0.06$$

Hence, given the previous test characteristics, a finding of 39% apparent prevalence suggests that the true prevalence is actually negative! Of course, a negative prevalence is nonsensical; it means that the disease is not present. With so many FPs resulting from the low specificity, the practitioner needs an apparent prevalence well above this level to feel confident that any of the identified animals are truly infected. As an aside, the complement fixation test is only *presumptive* in U.S. Department of Agriculture rules; it must be confirmed by a highly specific test. The reasoning behind this should be apparent now.

Running Tests in Series: Test Batteries

Often, when investigating a potential disease in an individual or when working up a group- or herd-level problem, practitioners take "test batteries." Some of the more common examples lie in running clinical chemistry panels. Reference laboratories offer the option of running a variety of panels, each specialized for either a species or suspected condition. For example, the standard "small animal panel" or "equine panel" is made up of approximately 15 different derivations. The "food animal panel" often comprises 16 individual tests.

The earlier discussion of test qualities (measurement error, accuracy, discrimination, and precision) suggests an interesting, if rarely considered, problem in running panels. Each test has a certain ability in differentiating "normal" from "abnormal" based on the specific characteristics of the method and processing. Depending on where the test lines are drawn, therefore, each test has a certain likelihood of misclassifying an individual. If the tests are independent (and some of them are not, making the following a little pessimistic), the probability of a panel's coming back with at least one "false-abnormal" finding is equal to the product of each test's likelihood of falsely categorizing a normal animal as abnormal. The ranges shown on most clinical pathology reference tables are the mean result from a significant number of seemingly normal animals plus or minus 2 SDs. When a normal distribution is assumed, this means that roughly 97% of all normal animals should fit in the range. Hence, the practitioner starts out knowing that 3% of all normal animals will not fit in the range (i.e., a 3% FPR). For some species the numbers used to develop normals can be quite small—with reindeer, for instance, the published normals probably are not as valid statistically as those for swine or cattle.

Suppose a baseline panel of five unrelated tests is run on an otherwise healthy goat. If the tests were completely independent, the probability that at least one test will yield a false positive is as follows:

$$P(\geq 1 \text{ FP} \mid 5 \text{ tests @ } 3\% \text{ FPR}) = 1 - (0.97^5)$$
$$P(\geq 1 \text{ FP} \mid 5 \text{ tests @ } 3\% \text{ FPR}) = 14\%$$

Hence, when an abnormal finding appears on an apparently healthy goat, there is a 14% chance of its being a red herring. If this were a testing program on five goats, there is close to a 70% chance that one of them will get an "abnormal" result. If the practitioner simply is looking at which animals may need closer scrutiny—that is, if it is being done as a *screening test*—there is little danger of an occasional misclassification. However, if the test is a test for *Brucella*, tuberculosis, or vesicular stomatitis, in which a positive test means the animal will be slaughtered and the farm or stable will be quarantined (bringing with it all the immediate and long-term financial, personal, and psychological losses), a misclassification can be disastrous. Thus practitioners should never make diagnoses based on tests alone.

Multiple Tests: Screening and Diagnostic Strategies

The previous examples looked at using a single test in a vacuum. Since practitioners do not operate in a vacuum, more than one test can be used. A technique that attempts to use the greatest strengths of individual tests is using tests as *screens* and as *diagnostic tests*. A screen, in the classic sense, aims to identify the maximal number of diseased individuals, at the expense of incorrectly identifying nondiseased individuals as diseased. In the terms used previously, a screen has a high sensitivity (low FNR). Its specificity is not a priority. A diagnostic test, therefore, is used on the population identified as positive to a screening test. It attempts to winnow out the screening test's false positives. Hence, a diagnostic test demonstrates a low FPR (high specificity).

The idea is to use the tests in situations that take advantage of each test's power, yet protect the population from the tests' weaknesses. Biologically the process offers the most efficient way to measure individuals' status within a population. Yet even this process is not perfect; trade-offs are made even when test situations are optimized. This trade-off

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TABLE 2-4

*Hypothetical Set of Two Tests**

HI-SE STRATEGY

	DZ+	DZ−						
T+	32	14	46	SE	=	0.97	**Inaccurate results**	
T−	1	53	54	SP	=	0.79	Cull	14 (FP)
	33	67	100	PVPT	=	70%	Keep	1 (FN)
				PVNT	=	98%		

HI-SP STRATEGY

	DZ+	DZ−						
T+	28	2	30	SE	=	0.84	**Inaccurate results**	
T−	5	65	70	SP	=	0.97	Cull	2 (FP)
	33	67	100	PVPT	=	93%	Keep	5 (FN)
				PVNT	=	93%		

SCREEN STRATEGY: HI-SE, THEN HI-SP

	DZ+	DZ−		DZ+	DZ−					
T+	32	14	46	27	0	27	PVPT	=	100%	
T−	1	53	54	5	14	19	PVNT	=	92%	
	33	67	100	32	14	46	**Inaccurate results**			
							Cull	0	(FP)	
							Keep	6	(FN)	

*One test has a high sensitivity *(Hi-SE strategy)*, and the other has a high specificity *(Hi-SP strategy)*. Each test is run, by itself, on a group of individuals in which the group prevalence for the disease in question is 33%. Then they are run in series, using the standard "screening and diagnostic" test strategy *(Screen strategy)*; the highest SE test is run on the whole group and the high SP test is applied to those testing positive to the first. The end result of the screening-diagnostic strategy is that the dual test scheme displays the highest average predictive value compared with either test alone; it removes the false culls yet returns the most diseased animals back to the herd. *FN*, False negative; *FP*, false positive.

TABLE 2-5

*Continuation of the Process from Table 2-4**

SCREEN STRATEGY: HI-SP, THEN HI-SE (SP, SE)

	DZ+	DZ−		DZ+	DZ−					
T+	28	2	30	27	0	27	PVPT	=	100%	
T−	5	65	70	1	2	3	PVNT	=	92%	
	33	67	100	28	2	30	**Inaccurate results**			
							Cull	0	(FP)	
							Keep	6	(FN)	

*This time the two tests are run in the reverse order: the highest specificity *(Hi-SP)* test is run on the whole group and the high sensitivity *(Hi-SE)* test is applied to those testing positive to the first. The end result of the "reversed" screening-diagnostic strategy is the same as for the standard screening-diagnostic strategy from Table 2-4.

weighs the relative merits of minimizing false positives versus the false negatives. One, of necessity, will be higher than when at least one of the tests is used alone. The following example helps to illustrate this.

Assume a practitioner wishes to identify individuals with a communicable disease in order to cull them. Further assume there are two tests: one with a high sensitivity and a relatively low specificity, and the other having just the opposite. One of three testing strategies can be chosen, as shown in Table 2-4: (1) only the high sensitivity test ("Hi-SE"), (2) only the high specificity test ("Hi-SP"), and (3) the Hi-SE test as the screen and the Hi-SP test as the diagnostic test ("Screen strategy"). The 2 × 2 tables in Table 2-4 show the results of each strategy when used in a population with a 33% disease prevalence.

This is all great. The screen-diagnostic method yields a higher average PVPT and PVNT than either test alone. It wrongly culls fewer animals, too. However, it allows more diseased animals to stay in the herd. Plus it runs 46% more tests than either test alone.

Just for fun (this *is* fun, right?), what would happen if the analyst ran the screen-diagnostic strategy just the opposite (i.e., using the Hi-SP first and following with the Hi-SE)? Table 2-5 uses the same data as before, simply with the order reversed.

The outcomes are *identical!* This is actually a pretty intuitive result, since the test results are a matter of multiplying a set of efficiencies against the initial population and then following with a second set of efficiencies being multiplied against the result of the first multiplication. Since multiplication is order independent (i.e., 3 × 5 = 5 × 3), they should get the same answer. If, biologically, it doesn't matter how the screening-diagnostic test strategy is run relative to the comparative SE and SP of the involved tests, the strategy's order must be chosen based on other criteria.

Economically Choosing How to Run a Screening-Diagnostic Test Strategy. The choice depends on the relative cost of each test. The SE-SP strategy runs a total of 146 tests, with 2.2 SE tests per SP test (100, 46 respectively). The other strategy, SP-SE, requires only 130 tests total, with 0.3 SE tests per SP test (100, 30, respectively). These values can be placed into an equation, setting the one strategy equal to the other, and solving for the relative costs that fulfill the equality:

$$100\text{Hi-SE} + 46\text{Hi-SP} = 100\text{Hi-SP} + 30\text{Hi-SE}$$
$$70\text{Hi-SE} = 54\text{Hi-SP}$$
$$(70/54)\ \text{Hi-SE} = (1)\ \text{Hi-SP}$$
$$(1.296)\ \text{Hi-SE} = (1)\ \text{Hi-SP}$$

Algebraically, the rough break-even price ratio of the two is Hi-SP = 1.3 × Hi-SE. If the Hi-SP test costs more than 1.3 times the Hi-SE test, the SE-SP strategy should be chosen. If the Hi-SP test costs less than 1.3 times the cost of the Hi-SE test, the SP-SE strategy should be chosen.

Using System Efficiency Measures (Number Correct Versus Number Incorrect Classifications) as a Method to Choose Between Two Screening-Diagnostic Testing Strategies. The SE-SP strategy yielded over six correct calls for every incorrect classification (126 versus 20). The SP-SE method, though, achieved a greater than 15:1 (122 correct to 8 incorrect) ratio in correct to incorrect classifications. As in the prior example, a value could be placed on each test outcome (i.e., each false positive, false negative, true positive, and true negative). Then the opposing screening-diagnostic test costs could be compared against this valuation to select the optimal strategy.

With either type of analysis, choosing between testing strategies requires more than knowledge of test efficiencies, since they both involve economic methodologies. Not surprisingly, that is the next topic.

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ECONOMICS

Economics has been defined as the science of allocating scarce resources between competing wants. It has also been defined as the hard science of the humanities and the astrology of the hard sciences. Both descriptions fit. As a discipline, economics has tried to explain things as different as human motivation and the market price of a wheelbarrow. The techniques it employs are used to evaluate the past, appraise the present, and predict the future. As a working tool it is not perfect in performing any of those three functions.

Both private and public practice veterinarians involved in agriculture live in a world governed by economics. Private practitioners' decisions and recommendations have economic impacts on their clients and the markets to which the clients sell products. Veterinarians involved in regulatory occupations can have major impacts on a county, a state, an industry, or even a country. As a result, it is important for both segments of the profession to have an understanding of economic basics.

The majority of the learning curve in economics is concerned with digesting the nomenclature of the discipline. The language is peppered with a variety of abbreviations such as APR, TP, MVP, IRR, and others. It also uses jargon such as *utility, opportunity cost,* and *marginal value* and differentiates between seemingly synonymous terms such as income, revenue, and profit. Lastly, it uses a graphical and mathematical means of proving and disproving points of contention. Luckily, most of the vernacular and mathematics is simply a shell over common sense and logic.

As a discipline, economics is most commonly divided into two major areas of inquiry: *microeconomics* (mainly concerned with firms or groups of individuals [often called "markets"]) and *macroeconomics* (study of the function of whole economies on the level of countries or continental regions; it attempts to account for all facets of an economy such as unemployment, inflation, and relations between countries or regions). Both microeconomics and macroeconomics deal with supply and demand and the interaction of producers and consumers. Therefore a great deal of overlap exists between the two. Government regulations (certainly a macroeconomic function) affect individuals and markets. Further, markets can apply pressures that cause macroeconomic changes (look at the impact foreign automakers had on U.S. economic policy and international trade programs of the 1980s and how the inception of the North American Free Trade Association has altered the local markets and businesses on both sides of the participants' borders), and market trends are often analyzed using macroeconomic techniques. Whereas macroeconomic factors determine the landscape in which veterinarians and their farming clients operate, practitioners do not strongly affect the macroeconomic factors. Therefore this section primarily focuses on microeconomics as it relates to production and production medicine. However, in agriculture, macroeconomic trends can never be far from mind.

Supply and Demand

Supply, in economic terms, refers to the quantity of some item that producers are willing to create at a certain price. In the U.S. economic system, supply is determined almost exclusively by price: the higher an item's value, the more apt it is to be produced. *Demand,* in economic terms, refers to the quantity of an item that consumers are willing to purchase at a certain price. The more something costs, the less of it a consumer will buy. The radio may report on supply or demand, but in most cases they do not provide the full economic description because all they usually refer to is quantity. Remember, to be economically meaningful, *both* the quantity and price are needed.

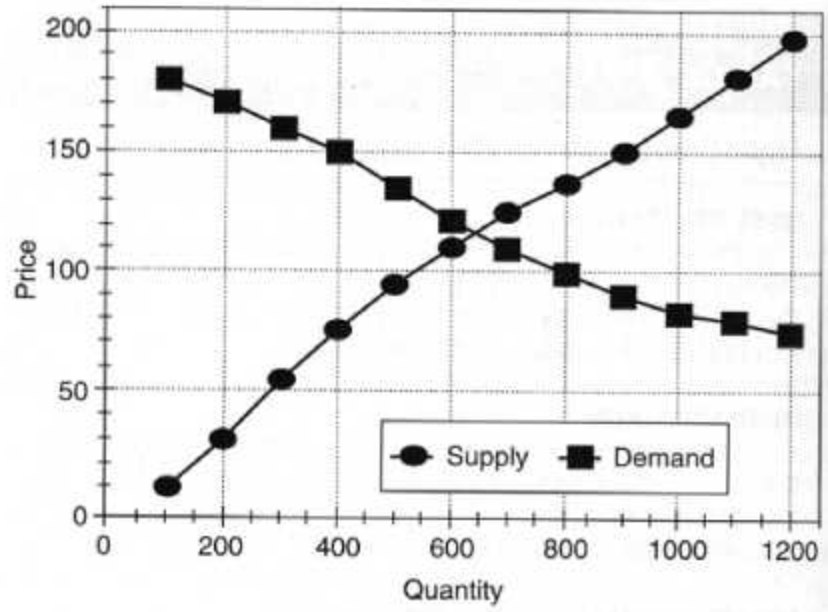

FIG. 2-17 Depiction of typical supply-and-demand response curves for a hypothetical product. As price of the commodity rises, more producers can afford to create the commodity, so supply goes up. Demand, however, decreases in the face of rising costs. The point where the two lines cross is the equilibrium point. This is the price and quantity combination where both supply and demand are satisfied. Left on their own, most markets move toward the equilibrium point.

Fig. 2-17 shows an example of supply-and-demand curves for some hypothetical commodity. They are increasing or decreasing curves, not merely straight lines. The point at which the two curves intersect is called the *equilibrium point* and is the price and quantity at which both curves are satisfied (i.e., supply equals demand). At other points along the curves, supply and demand are in *disequilibrium* and the market is unstable. This occurs often in the short run, but if left alone, prices will change such that equilibrium is once again reached.

In Fig. 2-18 the price shown as "A" is a disequilibrium price. At this point, to sell all the product, price must fall (the line connecting the two curves, points 1 to 2). Producers cannot afford to maintain this level of production, so they scale back (line connecting points 2 to 3). This low a quantity, however, does not meet demand, and price jumps (line 3 to 4). At this price, producers can afford to supply more, so quantity increases (line 4 to 5). This makes price drop, and the whole thing continues until equilibrium occurs once again. Adam Smith, the economist of colonial times, called this tendency for a market to move toward equilibrium an economy's *invisible hands.* The invisible hands are actually the summation of a number of individuals' decisions to produce and purchase a product. This pattern of economic behavior is referred to as the *cobweb theorem* for obvious graphical reasons.

Demand and Supply Analysis (Elasticity)

Different products have different shaped and sloped curves. Economists call the slope of a curve the product's *elasticity.* Elasticity of demand is a simple calculation referring to the relative change in quantity of a product demanded divided by the relative change in price. Supply elasticity looks to the change in quantity supplied divided by the relative change in price. If the slope is low (in most graphs such a line appears relatively flat), this is called *elastic;* it indicates that a large percentage change in quantity occurs when price changes only a little. If the change in quantity is low when

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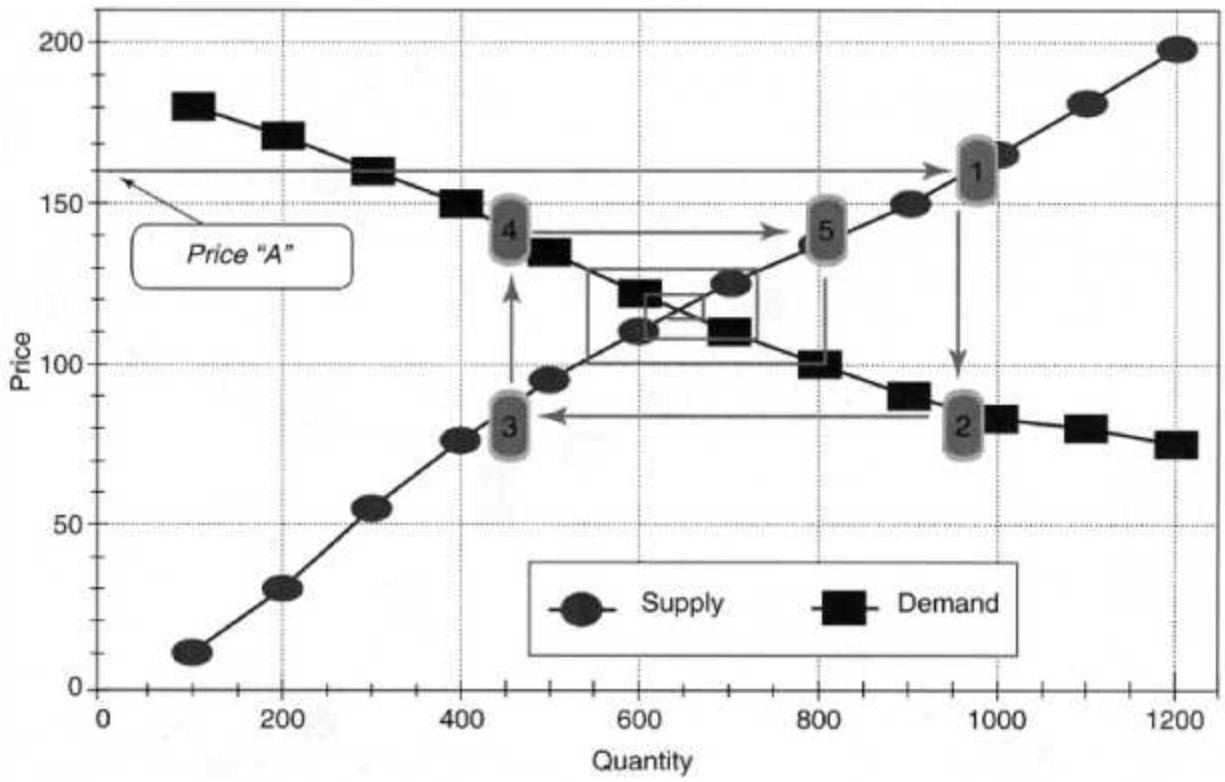

FIG. 2-18 Graphical display of the "cobweb" or "invisible hands" theory of market equilibrium. If price is set at a disequilibrium level *(Price "A")*, supply is greater than the quantity demanded *(1)*. This causes prices to drop to the point where demand will clear the market *(2)*; another disequilibrium price. This price, however, is below that which producers can maintain supply, so they scale production back *(3)*. Now supply is being outstripped by demand, so prices rise again *(4)*; yet another disequilibrium price, but closer to market equilibrium than before. At this high price more producers can operate in the market, so supply rises and once again exceeds demand *(5)*. This causes a continuation in the price-and-supply oscillation until the market settles at the equilibrium price and quantity, satisfying both supply and demand.

price changes a lot (in most graphs such a line appears relatively vertical), it is called *inelastic*.

Fig. 2-19 shows an instance in which supply is elastic (price changes approximately 100 units for a change in quantity from 200 to 1000) and demand is relatively inelastic (price changes approximately 200 units for the same change in quantity). This is an instance of market instability even at price equilibrium, since a minor fluctuation in price greatly affects supply (i.e., a small change in price results in a major change in quantity supplied), but it does not translate into a similar change in demand. This can set up a market, as Fig. 2-19 shows, in which prices oscillate wildly, causing the market always to be unstable. Hence, the producer is at risk. This situation is common for staple goods (bread, surgeon's gloves), low-risk actions (buying feed), essentials (semen for AI technicians, calcium solutions for dairies), and agricultural production in the short term. In these situations, market demand is relatively price sensitive, whereas production is not. Were the relationship reversed—that is, were supply inelastic and demand elastic—this would mimic the market for luxury items (yachts, caviar, jewelry) or risky endeavors (developing new products, starting new health programs).

Elasticity indicates a market's ability to react to changing times and conditions. As in Fig. 2-19, if both curves show inelasticity and elasticity, changes in market price can cause the market to "explode" as opposed to reaching equilibrium. Unfortunately, most of agriculture displays fairly similar short-term supply-and-demand functions, leading to farming's famous "boom and bust" cycles. Agriculture, particularly capital-intensive agriculture, can be quite prone to this unstable disequilibrium. For instance, once a sow farrows, there is little the producer can do to increase or decrease the number of piglets in the production system; if prices go up or down, the producer cannot change production to match. On the demand side, some products are quite elastic with price. For example, the demand for fishmeal may vary greatly if the price changes only a little relative to the price for other protein feed ingredients.

Production Function Analysis and Interpretation

To understand production, the reader, whether working in a veterinary practice, making widgets, working on the executive board of a zoo, running a laboratory animal resource center, or farming, must gain an appreciation for several dynamics of production. Understanding the relationship between costs, inputs, outputs, and returns provides a good idea how much of the product should be produced and if the producer can afford to expand. Fundamentally, understanding the costs of production allows for planning and realistically budgeting for the future.

Introduction to Production Functions: Total Revenue (Total Product)

Production functions are tabular schedules, graphs, or equations that relate a variety of costs of production with a firm's profitability. When graphed, they relate inputs to outputs and are called *production curves*. By convention, the units on the vertical axis are in units of returns (units of money, pounds of gain, eggs per hen) and the horizontal axis is in units of inputs (pounds feed, gallons of fertilizer, worker hours, units of money).

Fig. 2-20 depicts a production function developed from published feed requirements for growing beef calves at recent local North Carolina prices (National Research Council, 1996; North Carolina Department of Agriculture and

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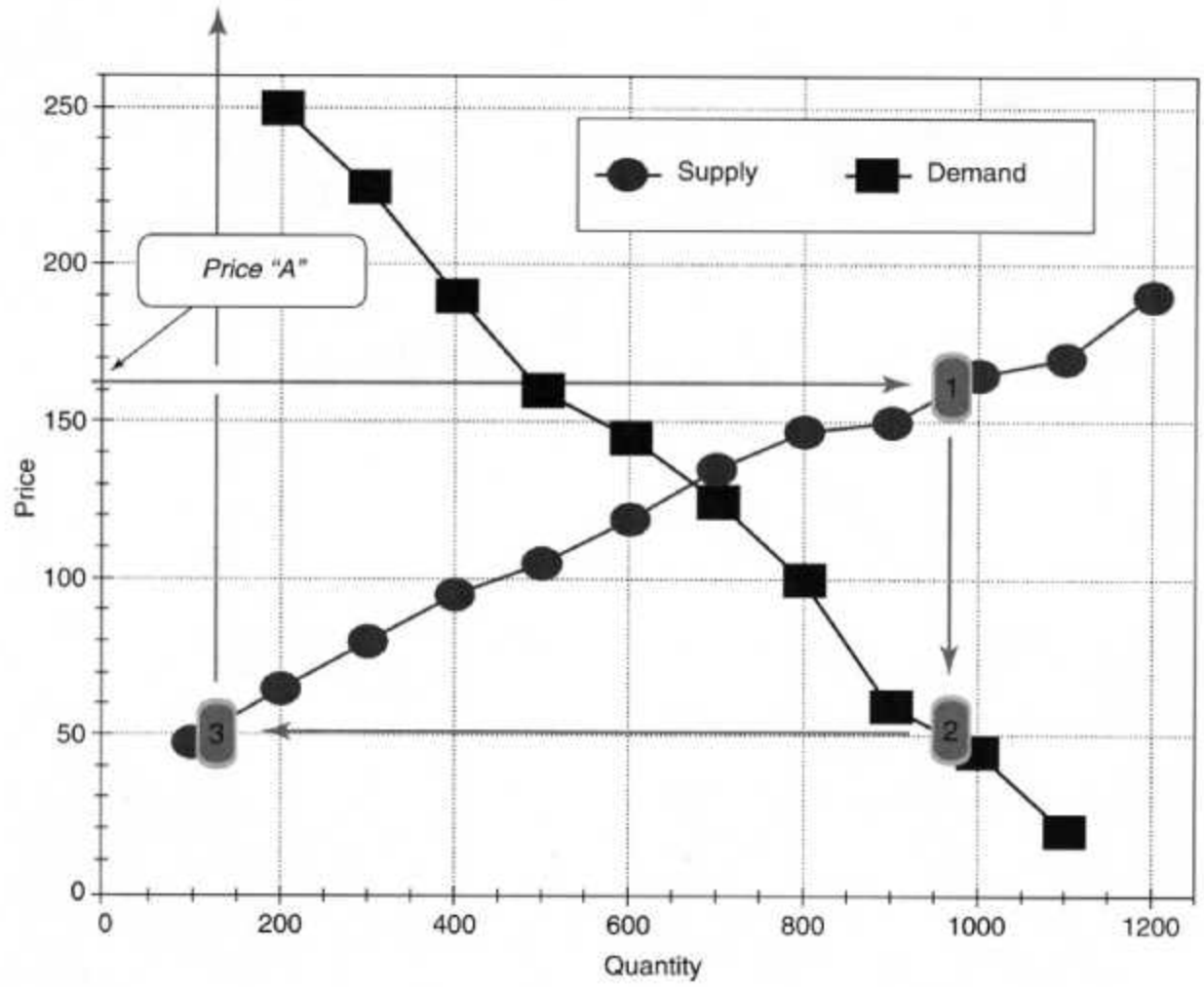

FIG. 2-19 Graphical depiction of a case in which supply is relatively elastic (horizontal orientation) and demand is relatively inelastic (vertical orientation). If price is set at a disequilibrium level *(Price "A")*, supply is greater than the quantity demanded *(1)*. Price drops precipitously because of the more vertical orientation of demand in this figure compared with Fig. 2-18, to clear the market at point *(2)*. This price, however, is much lower than that which producers can maintain supply. Only a few producers remain in the market, and supply then crashes *(3)*. At this extreme level of scarcity, price would need to skyrocket beyond the limits of the chart to cross the demand curve. As a result, disequilibrium pricing in such an unstable market causes the market to spiral out of control, establishing a "boom and bust" oscillation of prices and quantities.

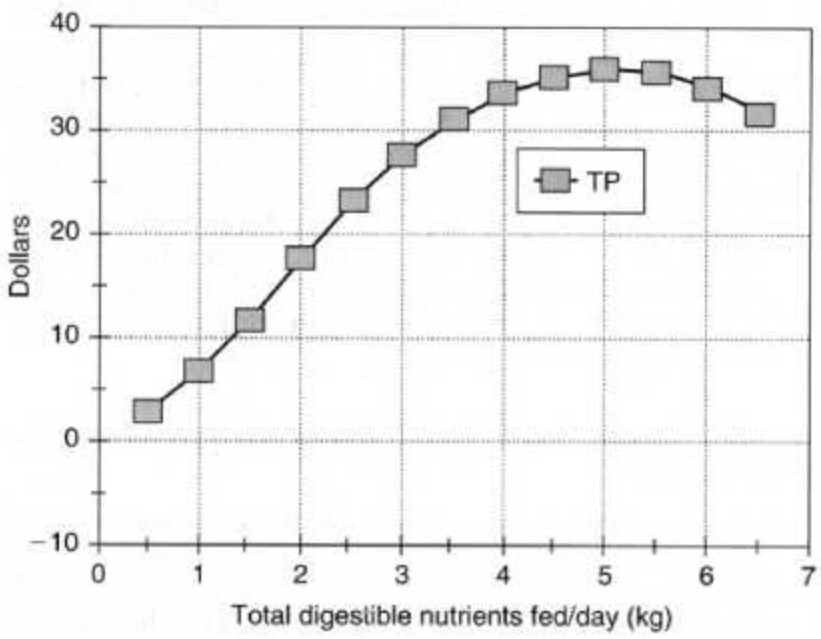

FIG. 2-20 Production function for raising beef steers in the North Carolina market (spring 1999). The total revenue or total product (TP) is the income expected by selling steers at market. The inputs here are feed inputs, measured as total digestible nutrients *(TDN)* fed per head per day. Note that the curve shows a slight sigmoid form from 0.5 to approximately 3 kg TDN. After that point it shows diminishing returns; adding more TDN/day yields a lesser return, until after 5.0 kg/day, returns actually decrease.

Consumer Services, 1999). It relates the income expected against the amount of feed given per animal per day, in units of total digestible nutrients (TDN). For the sake of this demonstration, the relationship has been smoothed out somewhat, but the trend is based on real data. *Total revenue* or *total product (TP)* is the overall revenue curve. It shows "diminishing returns," meaning that production is not a straight-line relationship with input. Like most TP curves, this one climbs quickly at the start, reaching a point of inflection somewhere at 2.5 to 3.0 kg TDN per day. After this it continues to rise but at an ever lesser rate. Finally, there is a point where, perhaps because the ration is too energy dense or requires too high a dry matter intake, the efficiency of production drops and the value of the next pound of gain becomes negative. This is a common finding; most activities reach a point of diminishing returns, whether they are time invested in studying, money spent on an old car, or number of beers consumed. After a point the "returns" on continued activity begin to drop. For this reason the practitioner needs to be aware not of *maximum* production, but *optimum* production. This requires knowing more than just the total output of a system.

Average and Marginal Product

One way to look at production is to evaluate the "average" production at each point on the line. *Average product (AP)* is

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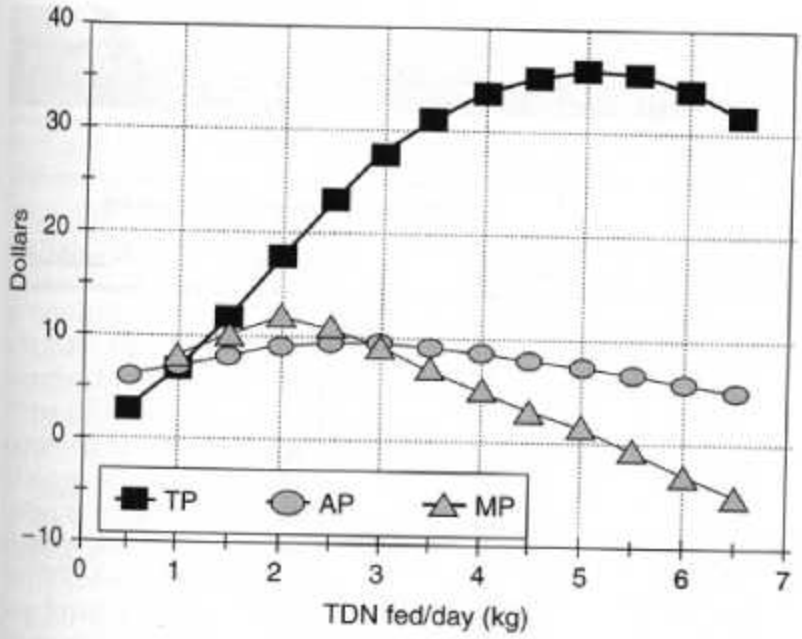

FIG. 2-21 Continuation of the steer beef production function analysis from Fig. 2-19. Here, average product *(AP; total revenue [TP]*/total digestible nutrients *[TDN]* input) and marginal product *(MP;* change in TP/unit change in TDN input). AP is an efficiency measure, whereas MP determines income for the last unit output. In this chart efficiency is maximized (i.e., AP reaches its highest) at approximately 3 kg TDN/day; however, the producer still can increase revenue by increasing TDN inputs until marginal product crosses 0 (i.e., the last unit input did nothing to increase revenue) at just over 5 kg TDN per head per day.

calculated by dividing TP by total units input. It is, then, the output per unit input for the production range. This curve for beef production is shown in Fig. 2-21. Note how the AP first climbs, then drops off. It reaches its peak at the TP-curve point of inflection. This is the point of highest average efficiency of the process. At the maximal AP, additional inputs lower efficiency but yield more income. Hence, maximal average return probably is not the most profitable production level. To get at profit, the analyst really needs to know not just where maximal efficiency lies, but at what point income is lost by increasing production. It makes sense that before that point, production would be near to being most profitable. The marginal cost of additional product is needed.

Marginal product (MP) is the incremental change in total product associated with a one-unit change in input. An example is shown as the other new line in Fig. 2-21. When MP is greater than AP, AP increases. MP and AP cross where AP is maximized. That is, any point of production beyond that level will be at a lesser overall efficiency. However, for a time after this point MP is still positive, it is still profitable to produce, even if it is at a lower per unit return. When MP finally goes negative, it no longer makes sense to produce more product—it no longer increases output. This occurs when the TP curve hits its maximum. Conceptually, it makes sense: If total income starts to fall, the value of each added unit of product must be *subtracting* from the overall income. That is, marginal values must be less than zero. Beyond this point it makes no sense to produce.

Stages of Production: Goldilocks Had the Right Idea

The TP, AP, and MP curves delineate three separate regions of production. *Stage I production* starts at the lowest production and ends where MP and AP cross: at maximal average efficiency. *Stage II production* ends where MP goes negative, where it does not pay to produce anymore. If a producer is at Stage I, additional input definitely will increase efficiency and profit. Hence, it makes no sense to operate at this low a production level. Any producer in Stage I should be working to move up to Stage II. A producer in *Stage III production* is lowering yield; total revenue is dropping. So it does not make sense to produce in Stage III. Stage II, then, is the rational region of production. Somewhere in Stage II is the optimal production level—money always will be lost below it and above it. Much like the story of Goldilocks and the three bears with their bowls of porridge, one stage of production is too hot (Stage I), one stage is too cold (Stage III), and one stage is "just right" (Stage II).

The value of staging production in the way just mentioned is that an analyst need not consider production ranges below maximal average efficiency or above where additional production cuts into revenue. Both usually can be calculated fairly easily, given that a few levels of production already exist. Staging, then, allows the analyst to concentrate on the area of production at which profit is at its highest. Of course, to find the maximal profit, the producer needs to look at *monetary costs,* not just units of input.

Costs of Production. Although production curves address units of input versus units of output, and these certainly can be put on a dollar-cost basis, there is more to "costs" than simply tallying inputs. Four costs are commonly discussed: fixed, variable, marginal, and opportunity. Fixed, variable, and marginal costs refer to the production process itself; opportunity costs relate to the costs incurred by choosing a nonoptimal action.

Fixed costs are those costs of an operation that do not change with level of production. They are incurred whether a farm is at maximal production or not; most still will apply even if the farm is not producing anything. Fixed costs can include mortgage payments, property taxes, insurance, equipment and building depreciation, warehouse rent, interest on capital, and management salaries. *Variable costs* represent those expenditures that increase with gains in production and decrease with drops in production. They are basically direct inputs into production, such as materials, seed, water, feed, labor, most power costs, and fuel. It is not, however, a straight-line relation with total output. This shows that, as in revenue, costs show variable returns to inputs. Remember that these definitions are time dependent. In the short term, such as a week or two, nearly all costs are fixed. However, as the time horizon increases, nearly all costs can be changed. *Marginal costs* are described in the next section. *Opportunity costs* are the costs of making a nonoptimal decision. Suppose a farm has the option of growing either winter wheat or barley. Historically wheat may be the best choice, but if this year a new brewery opens down the road, the local demand for barley (and hence its price) may rise. If the farmer chooses wheat, and barley returns $100 per acre more than wheat, that $100 is the opportunity cost of having chosen wheat.

Marginal Analysis. Just as the production functions show marginal products (the incremental increase in revenue by increasing production by one unit), the cost curves show marginal costs (the incremental increase in cost by increasing production by one unit). The relationship of marginal product and marginal cost determines a firm's optimal production point. Table 2-6 shows the production and cost schedule for producing cattle that has been used in this section. For this example a $5 per head per day fixed charge was attached to the production to cover taxes, mortgages, insurance, etc. Other costs were adapted from the current market data referenced earlier.

Marginal costs are the costs of producing one more unit of product. As defined before, marginal product is the revenue realized from one additional unit of product. Common

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TABLE 2-6

Data for North Carolina Beef Steer Production Function Analysis

	Estimated Costs of Production				Estimated Revenue-Product		
TDN (kg)	**Fixed**	**Variable**	**Total**	**Marginal**	**Total**	**Average**	**Marginal**
0.5	5.00	1.00	6.00	–	3.00	6.00	–
1.0	5.00	2.00	5.00	−2.00	7.00	7.00	8.00
1.5	5.00	3.30	8.30	6.60	12.00	8.00	10.00
2.0	5.00	4.50	9.50	2.40	18.00	9.00	12.00
2.5	5.00	6.00	11.00	3.00	23.50	9.40	11.00
3.0	5.00	8.00	13.00	4.00	28.00	9.33	9.00
3.5	**5.00**	**10.50**	**15.50**	**5.00**	**31.50**	**9.00**	**7.00**
4.0	**5.00**	**13.50**	**18.50**	**6.00**	**34.00**	**8.50**	**5.00**
4.5	5.00	24.00	29.00	12.00	36.30	7.26	1.60
5.5	5.00	31.00	36.00	14.00	36.00	6.55	−0.60
6.0	5.00	39.00	44.00	16.00	34.50	5.75	−3.00
6.5	5.00	48.50	53.50	19.00	32.00	4.92	−5.00

TDN, Total digestible nutrients.

*Optimal level of production can be selected as the level where Marginal Cost equals Marginal Product. In this table, optimal production occurs at or near 3.5 to 4.0 kg TDN per head per day (bold rows, circled values).

Data adapted from the National Research Council (1996) and North Carolina Dept. of Agriculture and Consumer Services (1999).

sense dictates that when it costs more to produce something than is given in return, it is time to stop. Until that point, however, each additional unit increases total profit, even if only a little. As seen in Table 2-6, it appears that at a quantity somewhere between 3.5 and 4.0 kg TDN input the marginal cost equals marginal product and is therefore the optimal level of production. This occurs well within the Stage II production, fitting the definition of the rational production region.

Most farms (or veterinary practices, for that matter) cannot perform constant and consistent marginal analyses of production; costs and revenues vary too much to make the effort worthwhile. However, they can identify fairly quickly Stage II production. A reasonable first step for a manager is to keep the firm's productivity in that range, since it is close to optimal. The better the records, however, the more apt an operation is to be able to identify an ever narrower range of production in which MC will equal MP and hence will be able to target inputs and outputs to truly maximize profit.

Where We as Veterinarians Err. (Or "Why did he drag us through all of this production function nonsense?"). A few moments spent looking at Fig. 2-21 and Table 2-6 will point to an error the veterinary profession, agricultural extension agents, and animal science researchers have been making for years: *Maximum efficiency is equated with maximum profit.* But the table and figure demonstrate that maximum efficiency results in the highest *average* return (somewhere around the $9.40 level, with 2.5 kg of TDN per day), not the highest *total* return (where AP is between $9.00 and $8.50 and TDN input is between 3.5 and 4.0 kg/day). *Therefore highest profit for an operation—whether a clinic or a farm, a car manufacturer or a restaurant—occurs at some point beyond maximal efficiency.* If a client is forced to maximize efficiency, the client is also forced into suboptimal profit regions.

Practitioners' health programs aim to maximize efficiency, as do the management programs and health goals and plans. Success of a program or management practice is often assessed by measuring "average daily weight gain," "herd-level income over feed costs," "average milk per cow per day," "income per worker hour," or "pigs weaned per sow per litter." These are measures of *average product* or efficiency, *not* measures of profit. They occur at the very beginning of Stage II production. Therefore, if a client stays at maximum efficiency, the client always will be straddling between rational and irrational (i.e., Stage II and Stage I) levels of production. Is that really where the client should operate?

Much to the practitioner's chagrin, and often against his or her heartfelt recommendations, clients often try to "squeeze" a few more feeders in a pen, or push the milking parlor "a little" beyond capacity. Practitioners should not be surprised when clients choose to operate at levels considered "inefficient"; they are maximizing profit just as they should. This is just a fundamental fact of production economics.

Costs of Animal Diseases

Overview of Disease Costs

Costs of animal diseases come in a variety of guises. There are the obvious *direct costs* of disease, such as medicine, treatment labor and equipment, and professional fees. These are out-of-pocket costs that are readily apparent and fairly easy to measure, but they often make up a minority of the disease's true costs. Other costs include *losses in production.* These costs of disease are more difficult to document. Diseases that cause morbidity also decrease feed efficiency, causing losses in production of meat, milk, eggs, and fur. However, debilitation also limits production of offspring and depresses genetic gain. These losses therefore must include not only the losses of production not realized, but also the losses in efficiency of what was produced. Animals provide economic value beyond that often considered within the bounds of agriculture, resulting in *nonagricultural losses.* In many parts of the world, disease costs are dominated by losses in labor or work performed by stricken

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animals (plowing, transportation, water pumping, grain grinding), by the loss of manure used for fuel (and the impoverishment of the environment when other fuel sources such as wood and ground cover are used instead) or fertilizer, and by the loss of liquidity (bartering potential and social status) and crop storage (feeding crops to animals converts that energy and protein to a form that the animal carries long after the crop is out of season) that animals provide for many people. Disease costs to *wildlife and companion animal populations* also can be great. Destruction of wild populations causes environmental degradation, allows foreign species to take root in an area, and can unbalance ecosystems. Companion animal losses, while often primarily accounted for in the direct costs of disease, also affect resource allocation (professional time and effort) that hinders other aspects of disease control. *Zoonotic disease losses* can be extreme. The losses of human labor, work efficiency, resource reallocation, medical expenses, and political support resulting from zoonotic diseases such as brucellosis, tuberculosis, and rabies cannot be overstated. Many of these diseases have, as their greatest costs, the expense of preventive programs and activities.

Details of Disease Costs

The direct economic losses from livestock diseases derive from biological losses. Measuring the financial losses can be approached using many of the same techniques used in biological epidemiology, with the addition of several factors specific to economics. Dollars, as well as morbidity and mortality, must be measured. Preventive and therapeutic inputs need to be included, as does labor. The concept of morbidity needs to include impacts on productivity and efficiency in addition to the traditional areas of subclinical and clinical disease effects.

The biological effects manifest themselves in a variety of ways: clinical, subclinical, carrier states, death. Each has its own economic impact. In addition to the economic toll arising directly from a disease, some economic impacts extend beyond a disease's biological effect on an individual animal or group. These include disease control activities, public health risks, genetic losses, impacts on management activities and the allocation of resources, limitations on marketing channels, reduced opportunity to enter into certain animal production activities, and the increased variability of farm output and efficiency (risk) and therefore reduced chance for survival of a farm or industry as an economically viable unit.

Direct economic losses to the production unit are the most obvious results of disease. These losses can be broken down into changes in revenues and changes in expenses (using the techniques derived from partial budgets). Disease control interventions have their impact by increasing revenues (or decreasing losses) or by reducing expenses. Some examples, with notes, are listed in Box 2-1.

Some points that are raised from the listing of disease and program costs deserve expansion. The costs of disease obviously depend heavily on current market conditions. The cost of a disease outbreak is greater when the market prices for animals are high than when prices are low because the relative value of the individual losses is greater. However, the overall financial picture of the farm on entering the disease losses is better in times of high prices. Therefore the outbreak may be more likely to bankrupt an operation when prices are low, even though the per animal costs are less.

Aspects of the disease and its losses undoubtedly are overlooked in the previous discussion and Box 2-1. However, no on-farm study approach to disease economics clearly provides answers to all of the aspects previously listed. In the example for pseudorabies in swine shown at the bottom of Box 2-1, on-farm studies can address the first seven to nine items and can provide some of the basic input data needed to do the calculations for items 8 to 14. The results can guide investigations and economic models that address items 15 through 20. Some items in this example (those dealing with trade or regional markets) require both macroeconomic and microeconomic evaluations to be complete.

Costs of Disease Control–Eradication Programs

Overview of Disease Control–Eradication Costs

Disease program costs can be broken into four large and overlapping categories. *Personnel costs* would include professional and lay staff. Costs of training, performing project related activities, and associated benefits are included here. Costs of *surveillance* are often great. Here, travel expenses, data collection, information processing and collating, reporting costs, laboratory expenditures, supplies, and administrative encumbrances are important. It should not be forgotten that surveillance involves both "seeing" and "telling." Many programs have high *compliance costs* associated with them. These can include costs of educating the public and producers (travel, personnel, supplies), administrative costs in monitoring and reporting program accomplishments, and the potential for indemnity payments as client compliance inducements. Lastly, a disease program analyst must include *costs of infrastructure* associated with a disease control program. These include, but are not limited to, purchase and maintenance of equipment (phones, data processing, communications, laboratory, vehicles), general supplies (paper, binders, uniforms), medication storage and transport, and general administration and oversight.

Again, many program costs overlap. Administration is mentioned several times, as are supplies and personnel costs. Partitioning such costs to various segments within a large regional program can be a daunting task. Much of the information needed for accurate cost accounting is, at best, difficult to generate for animal diseases. If you expand cost accounting into the wildlife and human loss arenas, the cost description becomes exceedingly complex and demanding because of the lack of hard figures and the general inaccessibility of much of the needed information.

Details of Disease Control–Eradication Costs

The costs of disease control are largely a function of the underlying structure of the group or organization running the program. For instance, the cost of a government level control program includes items and concerns different from that run by a veterinary clinic. A clinic is not likely to pay indemnities, yet needs to carefully account for its added costs in administering a program. With this in mind, here are a few added thoughts.

When accounting for personnel costs (especially in developed countries), the practitioner must be certain to account for benefits in salary considerations. Currently, an additional 25% to 33% in costs over salary can be expected to be incurred by an employer to cover benefits (health plans, medical insurance, retirement, etc.). Such costs are mandated by government fiat (local, state, or federal) and through private enterprise (labor unions and standards of practice).

Training costs have hidden expenses. Often practitioners do not take into account that training an individual in new skills requires taking that individual off his or her current job. This means either that job goes undone for the duration

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BOX 2-1

General and Specific Cost Considerations for General Animal Diseases and Specifics for Pseudorabies in Swine

CHANGES IN REVENUES WITH DISEASE CONTROL

1. Deaths avoided: estimating this can be difficult. A common approach is to take market values and deduct further variable costs needed to bring the animal to market. This is essentially a marginal costs exercise.
2. Improved weight gain–feed efficiency: for this, parameters to be economically relevant, costs of gain (feed costs) need to be assessed.
3. Increased reproductive efficiency: measuring the value can be a complex, situation specific task. It will be different for a commercial producer of terminal crosses versus a producer of breeding animals.
4. Increased milk, wool, eggs: the value is again a marginal analysis.

CHANGES IN EXPENSES WITH DISEASE (CAN GO UP OR DOWN)

1. Changes in feed costs
2. Drug, chemicals, vaccine costs
3. Veterinary services
4. Culling losses (commonly replacement cost minus salvage value)
5. Changes in physical facilities (should be their useful life if they are a major expense)
6. Downtime in the facility
7. Loss of genetic value (commonly handled by subtracting the value of a replacement animal with equal genetics)
8. Labor (can be difficult to capture; one approach is to ignore labor and then attribute any profit from a program as payment for labor and management efforts)

EXAMPLE: COST OF PSEUDORABIES IN SWINE

1. Dead pigs with clinical disease
2. Pigs dead of other disease, either via pseudorabies' sequelae or because management efforts directed at pseudorabies resulted in problems in other areas
3. Specific therapeutic measures against the disease or secondary diseases
4. Reduced litter size, abortion, or reproductive inefficiency
5. Reduced weight gains or feed efficiency, again either directly through the disease or because of management changes brought about by the disease
6. Costs for vaccination and preventive measures such as isolation and disinfection
7. Increased labor costs as a result of the disease
8. Loss from facility down-time during eradication or control (opportunity cost)
9. Loss of genetic stock, particularly in purebred or breeding stock production units
10. Lost value of product because of presence of disease
11. Loss of market for breeding or feeder pig stocks
12. New facility construction for herd repopulation
13. Costs for disease testing for eradication or control
14. Regulatory costs for surveillance and monitoring and control programs and administration
15. Increased risk and reduced attractiveness for swine production in regions known to have pseudorabies
16. Reduced entry into the swine business because of risks if pseudorabies enters a unit
17. Bankruptcy from reduced production or increased costs resulting in nonprofitability
18. Risk of bankruptcy to a profitable unit that cannot meet cash flow needs in the midst of a disease flare-up
19. Loss of export markets
20. Public health effects (not known to be important) or companion animal and wildlife effects (possible)

of the training (encumbering opportunity costs) or additional personnel must be hired or moved to cover that individual's activities (adding more personnel salary [often as overtime] and benefits).

Costs of infrastructure can be the limiting factor in program costs, especially when the unit of interest is a region or country. For instance, in a rinderpest and foot and mouth disease program run in Africa during the 1960s and 1970s, the costs and requirement for vaccine refrigeration capacity were enormous. Individual farms can face economically insurmountable infrastructure costs, though. For instance, a feeder pig respiratory problem may be largely due to poor waste management. Fixing this might require completely renovating the barns and waste control system—a huge cost that might not be warranted by any improved performance because of decreased respiratory disease. However, the infrastructure costs actually display strong competitive risk characteristics (see the earlier section "Is This 'Individual Versus Population' Thing Going Anywhere?" for review); hence they will benefit society (in the African example) or the farm (in the feeder pig respiratory disease example) in areas far beyond the control of mosquitos or pneumonia. This means that the actual costs of that infrastructure should be amortized over other parts of the system (society or farm) that benefit from its inception. Through such means of analysis expenses often can be justified that a single disease control result could not support.

Capturing What's Important

To understand the workings of any economic analysis, it is imperative to understand the basic foundations on which that analysis (indeed, *most* financial analyses) is built. Several aspects of technique are represented continuously throughout most economic analyses. These include some form of budgeting, or a means to list costs and returns. In addition, whenever programs or diseases have their effects over the long term, or the analyst wishes to account for relative financial or biological risks, most reports also take advantage of time discounting to the cash flows. An analysis that promotes a finding or a course of action also includes some decision criteria and occasionally considers several. Finally, most analyses attempt to put all the facets together

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into an overall indication of costs and returns comparisons between choices.

Other types of analyses exist, of course. Many get to levels of extreme complexity by using advanced modeling and statistical techniques. However, most are based on the processes just mentioned. Later sections look at other means of addressing problems.

Definition of "Partial Budget"

Though they are not often looked at in this way, budgets are economic models. A budget forecasts the future, creating a projection of costs and returns of some decision and its resulting actions. Everyone has created budgets. Some make them for household expenses, to qualify for a bank loan, or for costing out some project at work. The "partial" aspect can be a little tricky, but it is the facet of the technique that gives partial budgeting its power. In this instance, a *partial budget* attempts to include all parts of a problem that are related to a decision, but nothing more. For an element to be unrelated to a decision it must be unaffected by the decision and must not affect the decision itself. Many of the analyses used in animal agriculture are variations of partial budgets or take a partial budget and add in additional analytical techniques. All share the need to limit the analysis to essential items.

General Weaknesses and Strengths of Partial Budgeting. Because of the basic similarity of other techniques to partial budgets, it is important to understand how partial budgets work and where their strengths and weak points might lie. Deciding what belongs and does not belong in a partial budget sometimes can be difficult. Some basic guidelines exist. Again, anything that affects the decision or that is affected by the decision should be included. Usually, fixed costs are not included, since they are unaffected. Generally a partial budget does not attempt to account for risk or variability either, since the outcomes are assumed to occur precisely as computed.

The Family Vacation and Einstein. One thing to avoid in partial budgeting is the so-called Einstein effect. It is logically possible to tie nearly every item and event in the world to each other; some ties are just much more indirect than others. Practitioners of partial budgets suffer from the Einstein effect when they lose the perspective of being able to know when a tie becomes too indirect to count. The following few paragraphs show a ludicrous example of the Einstein effect.

Suppose you are taking a family trip and you need a budget. Certainly you need to account for meals and lodging costs. But what about new tires for the car? They might or might not be a part of the partial budget. Whether or not you go on the trip, you will eventually need tires, so you can't claim the tire acquisition will be the result of the trip—buying tires is unrelated to the trip because the decision is unaffected by taking the trip. However, if the tires are currently rotten, then the tires have to be purchased as a prerequisite to going on the trip. In this view, buying tires is related to the trip and should be included in the trip's partial budget, because the decision to purchase tires affects the ability to pursue the vacation.

What is the cost of taking the family car? One way to look at it would be to count the miles to be covered, divide by the average miles per gallon, and multiply by the cost of gasoline. You could add the cost of oil and coolant. Then again, you will be wearing out the vehicle by driving it, so a depreciation charge could be added to the trip, prorated by expected miles of life still in the vehicle versus what it will be worth at the end of the trip. What about insurance costs? You will be traveling long, exhausting miles in unfamiliar territory and increasing your risk of accidents, so an increase in insurance rates could be added. What if you sit in the car for too long and get a backache? What if it reinflames that old swimming injury, making it difficult for you to work when you get back? Then you'll lose some workdays and income.

What if your child chokes on a hamburger while riding in the car and has to go to the hospital because you also should have replaced the worn-out shocks when you did the tires? You will incur direct and immediate hospitalization costs and likely will see your health insurance rise in later years. What if, in your hurry to get your child to a doctor, you drive exceedingly fast, lowering the car's combustion efficiency and greatly increasing the vehicle's greenhouse gas emissions? That will increase your risk of skin cancer, possibly forcing you into an early retirement and increased old-age health costs.

What if you cause an accident while racing to the doctor, which is likely an increased risk because your back is already in spasms and you have exhausted yourself driving for so long in that constantly depreciating car? What if you kill someone in another car? Now your share of the societal costs in losing a productive member of the work force should be added, not to mention court costs and fines. What if that person were a brilliant Einstein-like child who was on her way to a major college whereupon she was going to make a discovery that would have led to a truly clean, environmentally sound, unlimited energy source for the world? Now how do you feel? Now how expensive was that trip?

That is the Einstein effect; watch out for it.

Parts of a Partial Budget: Solving a Problem with a Spreadsheet. A partial budget aimed at program evaluation essentially looks at two things: how a new program will change net revenues and net expenses. For example, a vaccination program might change revenues by adding weight gain efficiency and increasing the per unit value of the animals. That same program might change net costs by increasing vaccine expenses, decreasing sick animal costs, and decreasing morbidity. The budget then compares the revenue changes with the cost changes to give a net profit or loss. The following example helps put this into perspective and introduces the concept of sensitivity analysis.

Assume a client is looking at increasing profit by using intensive resource management (IRM) techniques (after all, it *is* what all the pundits are saying to do, and the pundits are always right). The data and assumptions are listed in Table 2-7. Essentially, this producer is above the North Carolina average in herd size and about average in historical weaning percentages and weaning weights. The prices vary, but they are in the ballpark for the southeastern United States. The literature (Lichtenwalner, 1996) suggests that intensive grazing allows stocking density to be increased by at least 10% to 15% on the same acreage of land, increasing the pounds of calf weaned per acre. Hopefully this translates into increased revenue, but it does not come without cost. The fencing needs to be established, maintained, and operated throughout the year. In addition, the pasture needs more intensive management. Is it worth it? This is a good problem to address with a partial budget. Again, the analyst needs to find out how revenues change and how costs change. Some physical factors will change: More cows are available, and they will have more calvings and (hopefully) wean more calves by going the IRM route. More fencing must be established and more pasture management must be scheduled. Financial factors will also rise; if the additional cows and fencing costs are financed, the interest charges will rise. And those new fences and pastures will not come free. So the analyst needs to account for all of this to make a good decision.

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TABLE 2-7

Assumptions for the Integrated Resource Management Decision on Whether to Intensify Pasture Management

Number	Variable	Value	Units
1	Current cow-herd size	30	head
2	Current weaning percentage	80%	of total
3	Current weaning weight (avg)	218	kg
4	Expected weaned calf value (avg)	$1.43	per kg
5	IRM costs		
5a	Interest rate (compounded monthlly)	10%	per year
5b	Fencing (box, posts, wire, gates, water, labor)	$750	for pasture
5c	Life of fencing	5	years
5d	Seeding–fertilizer	$105	for pasture
5e	Life of seeding–fertilizer	1	years
5f	Percent of cow and fencing financed (period = life)	100%	of total
5g	Cost of replacement cow	$250	per head
5h	Lifespan of cow	8	years
5i	Cull value of cow	$125	per cow
6	IRM allows increase carrying capacity of:	10%	per unit area

IRM, Intensive resource management.
Data from Lichtenwalner R: Management practices for more profit, *Animal Husbandry Newsletter,* April 1996, North Carolina Cooperative Extension Service, and recent local prices.

Fig. 2-22 shows a spreadsheet that addresses the issue. It is in the basic format of partial budgets: List the changes in revenue and the changes in costs, and compare the outcomes. Some of the values were calculated as shown in the following chart (The numbers refer to the line or "item" number from Table 2-7; the equation numbers [e.g., EQN1] refer to the following relative equation listed here):

	Current System	IRM System	Equation No.
Physical units			
No. of cows	Item 1	Item1 × (1 + Item6)	EQN1
No. of calves weaned	Item1 × Item2	EQN1 × Item2	EQN2
Calves weaned (kg)	EQN2 × Item3	EQN2 × Item3	EQN3
Revenues			
Value of calf weaned	EQN3 × Item4	EQN3 × Item4	EQN4
Annual cull cow return	(EQN1/Item5h) × Item5i	(EQN1/Item5h) × Item5i	EQN5
Costs			
Yearly fencing costs	—	Item5b/Item5c	EQN6
Yearly added replacement cow costs	—	($EQN1^{IRM} - EQN1^{CURRENT}$) × (Item5g/Item5h)	EQN7
Annual interest (avg)	—	(See below)	—
Yearly pasture maintenance	—	Item5d/Item5e	EQN8

Calculation of "Annual Interest (Avg)" Charge. Calculate total finance charge over life of each loan and then divide by term of loan. Quattro Pro 7 or another Windows spreadsheet "@" function can be used for this. It is called "@AMAINT" (amortized accumulated interest). Syntax for the equation is as follows:

@AMAINT(Principal, Int, Term, n)

where *Principal* = initial loan principal; *Int* = periodic interest rate; *Term* = term of the loan, expressed in number of total payments; and *n* = number of payments made (must be an integer from 0 to term). For the two values needed, this translates as the following:

Fencing: @AMAINT([Item5b × Item5f],[Item5a/12],[Item5c × 12],[Item5c × 12])/Item5c

Cows: @AMAINT([{$EQN1^{IRM} - EQN1^{CURRENT}$} × Item5g × Item5f],[Item5a/12],[Item5h × 12],[Item5h × 12])/Item5h

The partial budget from Fig. 2-22 suggests that, given these inputs, the IRM choice will yield an annual increase in income of approximately $363, or roughly 5% per year more than the current grazing strategy. A 5% increase in income may not be worth the added trouble—remember, these are in terms of "returns to management and labor," meaning this income must pay for management's extra efforts. Maybe the hassle of daily movement of cows is not worth getting an extra dollar a day.

Sensitivity Analysis: How Wrong Can the Estimates Be and Still Allow for the Right Decision? Suppose the analyst decides the daily movement of cows, as described in the previous section, is worth it but still wonders about some of the assumptions. What about some of the numbers? What if the operator is unable to keep control of more cows in a more intensively managed situation? He or she may not get as high a proportion of cows bred. The weaning percentage or weaning weights might drop if the producer is unable to manage the grass as well as is assumed here. If that happens, what will that do to the decision? These are all questions for *sensitivity analysis.*

Fig. 2-23 displays a sensitivity analysis on returns to management in which the weaning percent was allowed to vary from zero to 100% and all other values were left alone. The spreadsheet was recalculated at each new weaning percent. Note how the returns line crosses the zero outcome value threshold at around a 40% weaning percent. This means

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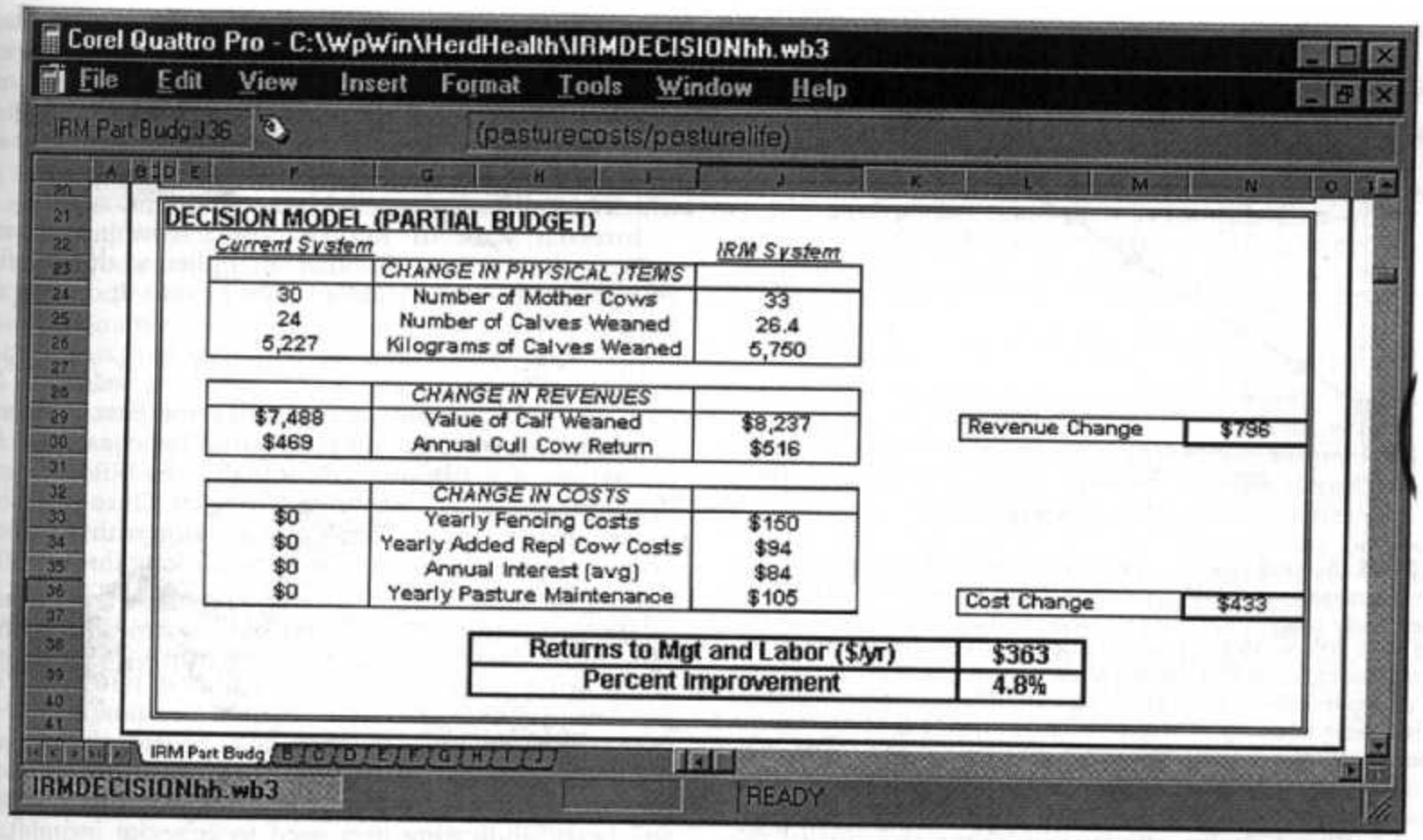

FIG. 2-22 Partial budget example for the Intensive Resource Management *(IRM)* problem, using Quattro Pro 8. See Table 2-7 for input data. The three sections on the left side of the window show, from top to bottom, the physical changes between the current and IRM systems, the revenue changes, and the cost changes. The summary changes for revenues and costs are listed on the right. At the bottom of the window is the difference between revenues and costs *(Returns to Mgt and Labor ($/yr)*, and a percent improvement in returns calculation. This model suggests that taking the IRM choice will increase returns by nearly 5%.

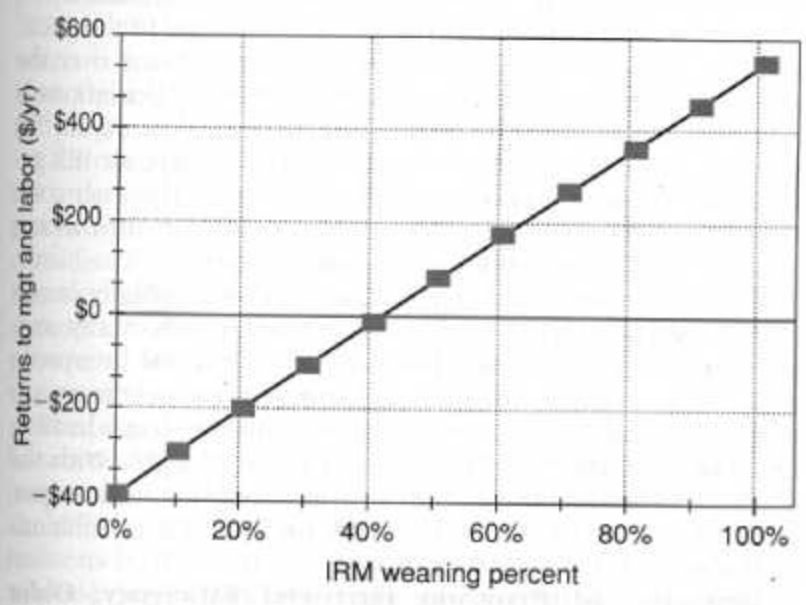

FIG. 2-23 One-way sensitivity analysis of the Intensive Resource Management *(IRM)* decision problem for weaning percent; all other values are per Table 2-7. The graph indicates that, even if the herd's weaning percent dropped by enacting IRM, the IRM program would still be optimal as long as the IRM weaning percent stayed above approximately 40%. The graph also suggests that if the herd were to improve its weaning percent from the current 80% to 90%, under IRM the herd's return would increase from approximately $363 per year to almost $500 per year.

that, all else being equal, switching to an intensive grazing program will pay, even if the weaning percent dropped to nearly 40%! Granted, the relative value of IRM drops as its weaning percent drops, but it is still the correct decision. This is a decision that displays a high degree of stability to weaning percentage—the likelihood of weaning percentage becoming this low is remote. Hence, the decision is a good one. Of course, to do it right, sensitivities would be run on other variables as well.

Suppose the client felt that the farm would support the high end of the increase in carrying capacity (i.e., a 15% increase versus the estimate of 10%). Would this increase the income sufficiently to make it more worthwhile? This can be shown if the value in Table 2-7, Item 6, is changed to 15%. With everything else left the same, the spreadsheet was rerun and showed the same basic analysis for changes in weaning percentages (Fig. 2-24). Increasing the carrying capacity to 15% (by 1.5 cows) approximately doubles the system returns at any given weaning percentage. Hence, this decision is critically affected by small changes in overall carrying capacity.

Time Value of Money

Present and Future Values of Money

The old adage states that "a dollar today is worth more than a dollar tomorrow." Anybody who has listened to the promises of deadbeat, no-pay clients knows this to be only too true. In financial terms a dollar received at some time in the future will have a *future value (FV)*, usually the face value of the money, and a *present value (PV)*, the discounted value of that future sum today. The difference in the value of that dollar between today and tomorrow determines the dollar's *discount rate (dr)*. This is usually a function of the *interest (i)* that could be accumulated if that dollar were invested today rather than tomorrow. As a result, money has a value directly proportional to when it is actually received.

Equations (for the Mathematically Inclined). The FV of an asset is equal to that asset's PV multiplied by some fractional discount rate over the given time horizon (number of

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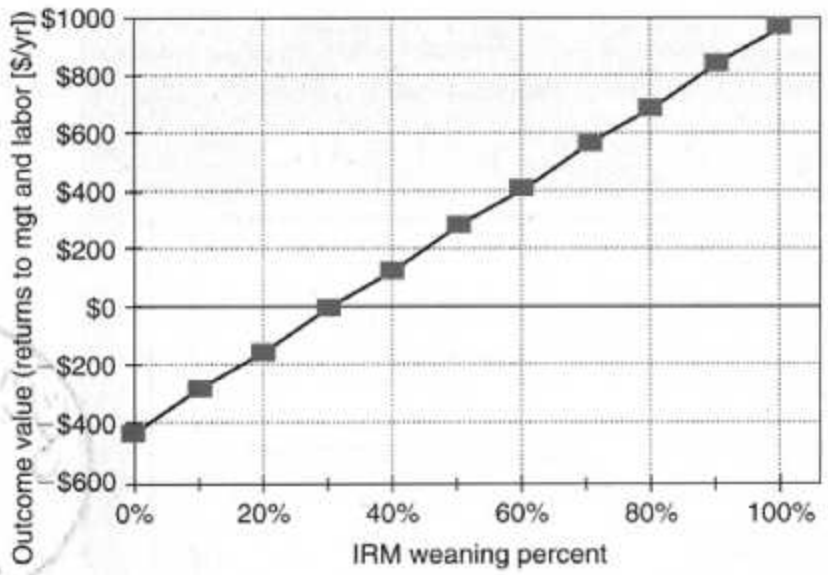

FIG. 2-24 Second one-way sensitivity analysis of the Intensive Resource Management *(IRM)* decision problem for weaning percent. In this sensitivity analysis the carrying capacity (Item 6 in Table 2-7) was raised from 10% to 15%; all other values are given per Table 2-7. The new analysis indicates that the increased carrying capacity will raise returns to approximately $700 at the current 80% weaning percentage. This is a near doubling of return on the project, indicating that the decision is sensitive to final carrying capacity.

periods). The discount rate is, in a sense, the reward the moneylender expects to receive for accepting the delayed payment.

$$\text{FV} = \text{discount factor} \times \text{PV} = (1 + \text{dr})\text{^no. of periods} \times \text{PV}$$

$$\text{PV} = 1/\text{discount factor} \times \text{FV} = [1/(1 + \text{dr})\text{^no. of periods}] \times \text{FV}$$

where the "^" sign indicates "taken to the power of."

As an example, what would John be willing to give Mary now if she promised to give him $100 in 1 year? If the yearly discount rate were zero, John should be willing to give Mary $100 right now ($100 \times [1/(1 + 0)\text{^}1]$). If John knew he could make 12% by investing that $100 over the same year, he would need to get $112 ($100 \times [(1 + 0.12)\text{^}1]$) just to break even (or to avoid an opportunity cost). If Mary held steady at only offering $100 in a year, John could only give her $89.29 ($100 \times [1/(1 + 0.12)\text{^}1]$) without incurring an opportunity cost on the transaction. In other words, for accepting the limitation of not having access to his $89.29 for 1 year, John would expect to be given $100. All modern spreadsheets, and most business calculators, perform time value of money calculations, so the above equations are not necessary to remember.

Net Present Value. *Net present value (NPV)* is a common decision criterion in economic analyses. The next section shows an example of calculating a cash flow's NPV. The NPV of a *one-time investment that yields a constant return* is simply the present value of that investment minus the current cost of that investment. This shows whether the opportunity is worth more than it costs.

$$\text{NPV} = \text{PV} - \text{required investment} = (1/[1 + \text{dr}]\text{^no. of periods} \times \text{FV}) - \text{required investment}$$

NPV calculations for investments showing *uneven but regular payments,* as shown by the following equation, can get quite complex to do by hand or calculator. Again, modern spreadsheets handle all the calculations needed. In this equation "V_x" indicates the difference in PV and costs in the time period "x." The equation is only the individual present values summed over the entire timeframe.

$$\text{NPV} = V_0 + V_1/(1 + \text{dr})^1 + V_2/(1 + \text{dr})^2 + \ldots V_n/(1 + \text{dr})^n$$

$$\text{NPV} = \text{COST}_0 + \text{PV}(\text{REV}_1 - \text{COST}_1) + \text{PV}(\text{REV}_2 - \text{COST}_2) + \ldots \text{PV}(\text{REV}_n - \text{COST}_n)$$

NPV calculations tell the analyst what discount rate is most appropriate for a cash flow. An NPV analysis, when applied to a program's cash flows, provides information on whether the program's cash flow exceeds that of the test discount rate. Also, NPVs are reported as either positive or negative to show which of the parties is realizing a gain and which is realizing a loss.

Internal Rate of Return. The *internal rate of return (IRR)* is the discount rate that, if applied to the cash flows of a program, would yield an NPV of zero. It can be calculated as follows:

$$\text{NPV} = V_0 + V_1/(1 + \text{IRR})^1 + V_2/(1 + \text{IRR})^2 + \ldots V^n / (1 + \text{IRR})^n$$

Finding an IRR is done by trial and error. First, select some discount rate, say 0%, and plug it into the equation. If NPV is >0, raise the IRR guess. Eventually, the IRR is narrowed down to a number generating NPV = 0. Once again, computer spreadsheets are capable of working with IRR calculations and prevent the headache of working through all the arithmetic.

There is a problem with some IRR calculations, specifically those dealing with cash flows in which values go up and down. For instance, if the practitioner purchases a large piece of equipment (a radiology unit, for example), the cash flow representing that purchase may be strongly negative in the first year (negative, because the practitioner had to fork over a lot of money for the unit), then may go positive for a few years (indicating it is used to generate income), and then may go negative again some time in the future when the cathode tube needs to be replaced. Such cash flows are notorious for leading IRR analyses astray because a very low interest rate and a very high interest rate usually can be applied to such cash flows and cause the net present value to go to zero. Because IRR calculations start with an educated guess, which of those two interest rates (and there may be more than two!) the algorithm settles on is due to the guess, not any special mathematical importance of one over the other. A second potential problem with IRR calculations is that they are indifferent to the direction of flow. In an IRR analysis, both the borrower and the lender have an IRR exactly the same; it doesn't matter which way the cash goes. Most businesses consider the direction of cash flow as important—IRR does not give that information.

For the reasons just listed, the NPV rule usually is recommended for deciding between investments. Many analysts, however, prefer IRR because of its ease of interpretation. It is indeed simpler in concept to get across to end-users, and as long as the project under consideration has a fairly even cash flow, they will be all right. With the ubiquity of financial calculators and spreadsheets, however, it is not asking too much to back up any IRR calculations with regular NPV determinations.

Measures of Program Financial Efficiency: Older Measures That Do Not Use Time Value of Money Calculations. Measures of financial efficiency are used to decide among competing proposals. The NPV and IRR indices just mentioned are two measures that use time value of money techniques. Not all criteria do. Older techniques for choosing among differing investment opportunities exist and are still used. They usually are variations on a *payback period scheme* or a *book-rate of return*. A payback period simply looks at the time it takes to recoup the start-up costs of a program. For example, if a program costs $100 to start, and that program pays back at $50 per year, the payback period will be 2 years (ignoring the time value of money). Payback periods, however, are ad hoc in their choice of a cut-off date; they ignore the long-term benefits and costs of a program and can be misleading if the analyst is not careful. Book rate of return looks at average percent returns and decides on pursu-

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ing an option by determining if it exceeds the return on a farm's portfolio of investments. In addition, book rate of return does not consider time value. Further, it looks at accounting valuations, not cash flows. Lastly, and this holds for both, the decision criterion is often arbitrary. A company may compare average book rates of return or payback periods against its current projects' values. As a result, successful producers with high rates of return on existing operations may reject good projects, and producers with low rates of return may accept almost any project. One last technique to measure program value is *cost efficiency*. This looks at costs to achieve some predetermined outcome, such as a certain level of disease prevalence or a proportional decrease in mortality. Cost efficiency is the only way to deal with programs whose returns are not quantifiable. It is shortsighted, though, since it is another form of payback analysis. Hence, it suffers from the same inability to look at outcomes beyond the predetermined endpoint.

Benefit:Cost Analysis: Using Time Value of Money, Efficiency Criteria, and Partial Budgeting

Definition of Benefit:Cost Analysis

Benefit:cost (B:C) analysis is the tool to use when looking at a program with high start-up costs and gradually accumulating benefits. Benefits are not always economic, however. Societal benefits from programs (increased public safety from animal-borne tuberculosis, for example) are difficult to quantify and simply may be listed in a qualitative fashion for consideration.

Several steps are common to most B:C analyses. First, the investigator must have epidemiological and economic data demonstrating the impact of the disease in question. Second, the biological and political feasibility of potential programs must be evaluated. For example, one way to get rid of PRRS would be to get rid of the national pig herd entirely—which is biologically feasible but not politically possible. Next, the analyst needs to evaluate the costs and benefits of the programs under investigation. This requires documenting the costs of disease, both direct and indirect; the costs of the program(s), both direct and indirect; social effects, both positive and negative; and an evaluation of the time horizon considered and the discount rate to be used (Hanson and Hanson, 1983). Fourth, the analyst needs to select the most appropriate decision criterion. Last, the exercise is incomplete until sensitivity analyses are performed on numbers that may be estimates.

The premise behind B:C analysis is that, for a program to be worthwhile, its long-term benefits should outweigh its long-term costs. As such, it is a form of partial budgeting. The difference is that B:C attempts to account for long-time horizons by discounting future costs and returns (i.e., time value of money) in establishing an overall program value. This requires understanding the time value of money and the effect of discount rates on program values. A variety of topics that go into a B:C analysis have been discussed. Time and space do not allow for a full example of the process. Instead this section looks at two programs, assuming that the partial budgeting aspect of the programs has been accomplished and that work can begin on the B:C part of the study. Table 2-8 assists in depicting this process of discount rates and B:C analysis.

Two programs are available. In total dollars the two are equivalent; however they show differing cash flows. Program A has a large cost for the first 2 years, then no costs. It returns a constant benefit over the time covered. Program B has lower early costs, but they continue for an extra year. Program B's returns increase throughout the program. The two columns titled "PV @ _%" list *time value conversion factors*. These convert a dollar given in the future at a certain discount rate. For example, at 8% interest, a dollar given 2 years from now is worth 85.7 cents (1/[1.08^2] = 0.857). At 12% it would be worth 79.7 cents (1/[1.12^2] = 0.797). Table 2-8 compares the two programs using two different discount rates, 8% and 12%.

In out-of-pocket costs, there is no difference—both cost $900 and yield $2100. Again, with out-of-pocket costs, Program A reaches its payback (i.e., recoups its costs) in year 3. Program B achieves payback in year 4 and so would be considered the lesser of the two using this criterion. If the decision between the two programs were based on PV of either the revenues or the costs, the decision would be a toss-up. The PVs of the revenues, at either discount rate, would favor Program A because it has the higher earlier values. However, if the decision were based on PV of costs, the decision would go to Program B because it has the lowest earlier costs. Although strict analysis of PVs for only revenue or costs is done rarely these days, the technique might be seen in older papers. Obviously, it is not advisable to do this.

If, as is more likely, the decision criteria were net present value, Program A is the choice at either discount rate. For Program A the NPV at 8% (819) is 20% greater than the NPV at 12% (683). For Program B the 8% NPV is 29% greater than the 12% NPV (723/559); the higher discount rate is "harder" on the program with returns increasing with time.

Based on B:C ratios, the two programs are essentially equivalent at equal discount rates. Both return, on discounted values, nearly $2 in revenue for each dollar invested. This is a good measure in that what it means is intuitively clear. The downside of B:C indexes is that they do not recognize magnitude of yield. For instance, had Program B's cash flows been 1/10 of those listed above, the program's B:C ratio would not change. If the decision maker could invest in 10 Program Bs, that would be fine. However, if only one Program B were available, the total cash return would be less with Program B than with Program A. Again, B:C ratios are indifferent to the magnitude of change.

Note what happens with IRR: Program A shows an IRR approximately 2.8 times as large as that of Program B! How can this be? Because of the cash flows' (i.e., Program A's earlier returns) responses to discounting, Program B's later, although larger, revenues are diminished enough to make its overall return less attractive compared with that of Program A.

The weight of the "opinion," then, seems to be toward Program A. It is favored by payback periods, NPVs, IRRs, and (although barely) B:C ratios, with all of this over two differing discount rates. The fact that the payback period favors the program may be of little interest, but it may help in selling a program to a producer. The fact that it returns its investment sooner than the other can be a powerful motivator.

The decision is not as easy with some programs (Rougoor et al, 1996). At times the criteria may disagree. In those instances the analyst can do either of two things: Pick the criterion that makes the most logical sense, or interpret the different outcomes as suggesting there is little financial difference in the programs. When this occurs, the analyst can use other, nonfinancial means of choosing among programs.

MAKING QUANTITATIVE CLINICAL DECISIONS

Statistical Significance Versus Clinical Significance Revisited

The H.O.T. statistics section on the chi-square test briefly touched on the difference between statistical significance and clinical significance by illustrating the use of the odds

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TABLE 2-8

*Example of Benefit: Cost Analysis**

Year	PV @ 8%	PV @ 12%	Program A Benefits	Program A Costs	Program B Benefits	Program B Costs
1	0.926	0.893	350	400	0	300
2	0.857	0.797	350	500	220	300
3	0.794	0.712	350	0	320	300
4	0.735	0.636	350	0	420	0
5	0.681	0.567	350	0	520	0
6	0.630	0.507	350	0	620	0
Total cash flow			2100	900	2100	900
Payback period			within 3 yr		within 4 yr	
PV	@ 8%		1618	799	1496	773
PV	@ 12%		1439	756	1279	721
NPV	@ 8%		819		723	
NPV	@ 12%		683		559	
B:C	@ 8%		2.0		1.9	
B:C	@ 12%		1.9		1.8	
IRR			128%		46%	

*Example includes the other decision criteria discussed before the section "Definition of benefit:cost analysis" in choosing between two programs. Program A yields constant benefits with a 2-year start-up cost. Program B yields increasing benefits and has its start-up costs spread over 3 years. Program A is clearly preferred when using either payback period, present value *(PV)* of benefits, net present value *(NPV)*, and internal rate of return *(IRR)* as the criteria. Program B is preferred when using PV of costs. The two programs essentially are equivalent when evaluated without time value of money calculations (total cash flow) and by benefit:cost *(B:C)* analysis (though B:C does slightly favor Program A). Note the IRR values (128% and 46%). It is clear that neither cash flow has anywhere near these levels of yield. These cash flows vary enough year to year to make IRR unreliable.

ratio to address magnitude of effect observed in 2 × 2 tables. The topic is now taken further with the introduction of new matters as well as more in-depth discussions of *P*-values.

Statistical significance versus clinical significance is an important relation to keep in mind. Everyone is aware that just because something is important statistically does not mean it also carries a clinical value. The difficulty lies in converting statistical outcomes to results that have intuitive meaning for clients and practitioners. The confusion between the two, however, deserves some attention, namely in making certain definitions are agreed on and some measures can be created that tie the two types of significance together.

The definitions of statistical significance and clinical significance are relatively straightforward, although sometimes they are easy to confuse. *Statistical significance* tells whether the conclusions drawn are likely to be true—the flip side of the classic *Type I* and *Type II* errors (declaring a difference exists when it actually does not or declaring no difference exists when one actually is there)—but gives no information regarding the degree of difference to expect if the experiment is run again. In terms of diagnostic tests (after all, the purpose of Type I and Type II errors is to "diagnose the truth" of the conclusions) the errors can be termed equivalent to sensitivity and specificity, as shown in Fig. 2-25. The diagram illustrates the four possible outcomes from a clinical trial testing the relative efficacies of two drugs. The columns indicate the actual, or true, state of affairs (i.e., Drug A is truly better than Drug B; Drug A is truly not better than Drug B), and the rows indicate the conclusions drawn from the clinical trial (i.e., the outcomes suggest Drug A is better than Drug B; the outcomes suggest Drug A is not better than Drug B). The upper-left corner cell indicates the outcome where there is a true difference, and the study identified it as such. The cell in the upper-right corner displays the outcome where there is no real difference, yet the study mistakenly identifies one as existing. The lower-left cell shows the outcome where there is a true difference, yet the study misses it. Finally, the lower-right corner signifies the outcome where there is no real difference, and the study correctly identified it as such.

The indices of study validity, α and β, then, are the complements of specificity and sensitivity, respectively. That is, α is the study's false-positive rate, and β is the study's false-negative rate. By convention, a "sensitivity" of 80% is accepted (i.e., somewhere in the Materials and Methods section of a typical report, the authors might say something to the effect of "...power is greater than or equal to 80%..."), and a "specificity" of 95% (i.e., in the same section, the typical manuscript might state "...significance was deemed to exist at the 5% level..." or something similar). The ability to "test" for the true difference in this hypothetical study is 8 of 10, and the ability to identify true nondifferences is 95%. But clinical tests are accepted (i.e., serologies, bacteriology, histology) with higher and lower false-negative rates and false-positive rates all the time—it depends on the situation. It makes sense, then, not to blindly accept or enforce an α of 5% and a β of 20% all the time.

Clinical significance shows the importance of the differences described—that is, the magnitude of effect observed—but gives no information whether the effect would repeat if we did the experiment again. Again, as shown in the H.O.T. statistics section on the chi-square test for contingency tables, tools to examine this are available. There are others.

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CONCLUSION DRAWN FROM A CLINICAL TRIAL	TRUE STATE OF AFFAIRS: Drug A is truly *better* than Drug B	TRUE STATE OF AFFAIRS: Drug A is truly *not better* than Drug B
Drug A is *better* than Drug B	**Correct (true positive)** *(1 − β = power)* Sensitivity	**Incorrect (false positive)** *(α = 1 − confidence)* 1-Specificity
Drug A is *not better* than Drug B	**Incorrect (false negative)** *(β = 1 − power)* 1-Sensitivity	**Correct (true negative)** *(1 − α = confidence)* Specificity

FIG. 2-25 Table (2 × 2) comparing the true state of affairs against a clinical trial's conclusions. This illustrates the similarities among the following: test sensitivity and specificity; α (alpha) and β (beta); study confidence and power; and true positives, false positives, true negatives, and false negatives. (Adapted from Sackett DL, Haynes RB, Guyatt GH, Tugwell P: *Clinical epidemiology—a basic science for clinical medicine,* ed 2, Boston, 1991, Little, Brown.)

For instance, if an analyst ran a clinical trial between two electrolyte solutions used for calf diarrhea in which "MagicLyte" gave twice the survival rate of "Cure-O-Lyte," and he or she did not state the statistical significance, or "*P*-value," of the study, another analyst would not know how likely the outcome would be to occur again if the test were rerun on a set of similar calves. If the statistical significance of the study were listed as $P = .33$, the odds are 2 to 1 that "MagicLyte" would, in a similar situation, prove better than "Cure-O-Lyte." That is, a 33% likelihood exists that "MagicLyte" performed best just from chance alone, and if the study were repeated, "MagicLyte" is more likely to result as the better solution. If the statistical significance of the study were $P = .01$, the odds are 99 to 1 that "MagicLyte," again, would prove better than "Cure-O-Lyte." That is, only a 1% probability exists that "MagicLyte" performed best just from chance. So, it is unlikely—*very unlikely*—that another, similar trial would disagree with this one.

The two types of significance—clinical significance and statistical significance—are related, therefore, by the fact that neither tells everything. *Statistical significance* gives information about the likelihood the outcome would occur again, given the same conditions. *Clinical significance* tells how big the effect was that the trial demonstrated—this one time. Hence, a treatment found somewhat better than another with a *P*-value of .001 causes clinicians to take notice regardless of the magnitude of response; rarely does information appear that offers such confidence. On further examination the analyst may decide that, although it is statistically significant, it does not cause "enough" clinical difference to be worth adding to the therapeutic armamentarium. In addition, a study finding that shows a major difference in effect (i.e., it suggests a 90% improvement in rate of return to normal function or performance), with a *P*-value of .18 (i.e., there is an 18% likelihood that the measured improvement in survival rates was simply due to random chance), also causes the analyst to take notice regardless of the probabilities. Clinicians rarely have access to something that can make such an impact. Analysts may not depend on this outcome, however, so other, secondary modes of treatment may be added, given the nearly 1 in 5 chance that the evaluated treatment will not change things. It is reasonable, then, for clinicians to weigh *both* indicators of outcome "quality," clinical significance and statistical significance, in determining whether to enact the new process or activity, contingent on the circumstances around the specific question at hand (Matthews, 1996).

Measures and Measuring Clinical Significance

Converting numerical statements of significance into terms that can be used directly by clinical decision makers is not that difficult. It requires a few new perspectives and techniques, but none are conceptually challenging. The new terms introduced are *absolute risk reduction (ARR),* a means of establishing total levels of effect, *relative risk reduction (RRR),* a means of standardizing effect, and *number needed to treat,* a quick summary calculation that brings statistical results into the realm of intuitive sense and makes them readily available for economic or epidemiological analysis.

For instance, consider the clinical trial results shown in Table 2-9, testing an all-in-all-out (AIAO) management strategy for grower pigs against a continuous flow (CF) management strategy (Ice et al, 1999). In this study the authors placed barrows of a similar background into either AIAO or CF houses, where various biological parameters were measured. In addition, half of each group was fed chlortetracycline. The authors report health and growth performance data for animals within each system and feeding treatment. In Ice's study, over all age groups, there was a significant difference in the severity of lung lesions between the two groups (AIAO < CF, $P < .02$), a trend to a lower prevalence of lung lesions in the AIAO group ($P = .06$), a difference in days on feed to reach market weight (AIAO < CF, $P < .02$), and a demonstrable negative correlation between total daily gain and severity of lung lesion ($r = -0.212$, $P < .001$). No significant effect of chlortetracycline feeding on growth and health parameters was found in this study. This example was chosen to demonstrate how a practitioner can use information from a study that was not directly presented in the study because the practitioner's point of interest was not a stated goal of the study.

Table 2-9 is arranged to show the derived results from the study and to calculate the measures of risk and return that indicate clinical significance. The data used here were derived using summary data from two figures in the report and are meant to compare outcomes of the 6-month-old barrow subgroups within this study (Ice et al, 1999). From inspection of Figures 3 and 4 in the manuscript, the study found that approximately 95% of the AIAO 6-month-old barrows displayed ≤10% lung involvement from pneumonic lesions (75/79). For the CF cohort, the same value is approximately 61% (47/77). For this exercise the treatment failure rates, listed in Table 2-9 as "adverse effects rate," are the points of interest. Hence, the failure rate for 6-month old barrows in the AIAO and CF groups is 5% and 39%, respectively. That difference in outcome failures should be enough to catch the practitioner's attention. But how does a practitioner translate such values into more intuitive information for decision making? By generating risk reduction and return indices.

ARR is the first and simplest means of adjusting experimental outcomes into results that have clinical meaning; it is merely the numerical difference in rates. By itself, it does not do much for analysts, but it is fundamental to the two other indices to be created. ARR shows the degree of disease reduction expected by using the new management practice (NMP), which in this example is AIAO, compared with the reference management practice (RMP),

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TABLE 2-9

*Calculation of Risk Reduction Indexes**

	Adverse Effects Rate		Risk and Return Calculations		
	Continuous Flow Management	**All-In, All-Out Management**	**Absolute Risk Reduction**	**Relative Risk Reduction**	**No. Needed to Treat**
Definition	*Reference Mgmt Practice (RMP)*	*New Mgmt Practice (NMP)*	*ARR = RMP − NMP*	*RRR = ARR/RMP*	*NNT = 1/ARR*
Calculation	$1 - (47/77)^{\dagger}$	$1 - (75/79)^{\dagger}$	$0.39 - 0.05$	$\frac{(0.39 - 0.05)}{0.39}$	$\frac{1}{(0.39 - 0.05)}$
Result	0.39	0.05	0.34	0.87	3.0

Data derived from Ice AD, Grant AL, Clark LK, et al: *Am J Vet Res* 60:603-608, 1999.

*For an experiment comparing continuous flow house management for grower pigs (RMP) against an all-in, all-out house management for grower pigs. The outcome being measured is the proportion of 6-month-old pigs that show >10% lung involvement with lesions compatible with pneumonia.

†Values derived from Ice AD, Grant AL, Clark LK, et al: *Am J Vet Res* 60:603-608, 1999, Figures 3 and 4.

which in this example is CF, based on the underlying population. In the case of the 6-month-old barrows, the ARR is found by subtracting the failure rate of the NMP from that of the RMP (CF − AIAO = 0.39 − 0.05 = 0.34). What does an ARR of 0.34 mean to the veterinarian or producer? It can be interpreted as the observed total magnitude of effect difference; from this study, AIAO-managed grower houses enjoyed a 34% decrease in the prevalence of animals with high levels of lung lesions. The reader should not feel bad if that does not appear as an intuitively amazing finding. Most clinically oriented persons share a lack of enthusiasm for ARR measures. They are not easily transferable to other situations, since other situations might show different base-failure rates. For instance, if a producer uses CF but has a 15% prevalence of slaughter pigs with 10% or higher lung lesion involvement, claiming that they will get a 34% reduction by going to AIAO makes no sense. However, as previously mentioned, it is not so much that ARR itself is enlightening, but what practitioners can do with it. They can calculate two other indices that are both of clinical interest.

RRR is one means of adjusting numerical or probabilistic outcomes into results with clinical meaning, by setting the magnitude of effect of a "new" or experimental treatment *relative* to the control-standard treatment. It is calculated by dividing the ARR by the adverse rate from the RMP. In other terms, it is the difference between failure rates of AIAO and CF, divided by the CF failure rate. For the current example this is ARR/CF = 0.34/0.39 = 87%.

The interpretation of RRR could be that, given the results of this study, we can expect an AIAO management system to achieve an 87% reduction in "adverse effects" (the prevalence of slaughter pigs displaying greater than 10% lung lesion involvement). In human medicine, RRRs of ≥50% are taken almost always as clinically significant. Those of ≥25% may or may not be taken as clinically significant (Sackett et al, 1991). Of course, the efficacy and cost of the NMP versus the RMP come into play here, as does the level of statistical significance. Hence, going back to the client with a CF management system and 15% "failure rate," the practitioner can expect that a switch to AIAO will decrease the client's failure rate to approximately 2% ([1 − 0.87] × 0.15 = 0.02). Both parties now can place this result in terms of economics, animal welfare, return on investment, or whatever decision criteria were chosen. But there is one more step that can really help.

Number needed to treat (NNT) is a simple transformation of ARR that yields a value that can be used intuitively by practitioners in deciding whether to use a new treatment or program. It generates, relative to each tested treatment and risk factor, the number of animals or groups (depending on how the data come to the clinician) that will need to be treated to prevent at least one instance of the adverse effect in question. It is simply calculated as the reciprocal of ARR.

The NNT value from Table 2-9 suggests that three houses need to be treated with the NMP (AIAO) to prevent at least one adverse event. Hence, NNT suggests the effort needed to reach a clinical target by giving a basis for examining costs and success rates. In the example from Table 2-9, if the cost difference between an AIAO management system for three houses was less than the cost incurred from having one house suffer the level and severity of lung lesions displayed by the CF management system, it makes economical sense to use AIAO. However, if the costs incurred through operating an AIAO strategy in three houses are greater than those incurred from having a house suffer the higher disease levels, then it does not make economical sense to switch to AIAO.

Example of Using the Risk Reduction Approach

Using the Risk Reduction Methods to Choose Between Therapeutic Options in Working with Papillomatous Digital Dermatitis

In a clinical trial (Guterbock, 1995) 147 Holstein cows with active papillomatous digital dermatitis (hairy heel wart) were selected from three California dairies and randomly assigned to five treatment groups. Two of the treatments are considered here: (1) ceftiofur, given 1 g IM q24 hr for 3 days versus (2) oxytetracycline, applied topically as 100 mg/ml

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TABLE 2-10

*Analysis of Choice Between Two Therapeutic Options**

Treatment Protocols	Estimated Cost per Cycle†	Treatment Failure Rate at 28 Days after Treatment‡	Absolute Risk Reduction§	Relative Risk Reduction‖	Number Needed to Treat¶
Ceftiofur *1 g IM q24 hr, for 3 days*	22.40	0.26	–	–	–
Oxytetracycline *100 mg/ml, cotton topically applied and bandaged 7 days*	32.00	0.06	0.20	0.77	5
SIMPLE COST ACCOUNTING					
If a treatment failure average cost is (midpoint of several estimates):			$65	Estimate	
If it takes five oxytetracycline treatments to prevent at least one treatment failure, added cost is:			$48	5 × (32.0 − 22.4)	
Therefore using oxytetracycline protocol saves approximately:			$17	65 − 48	

*Options are for bovine papillomatous digital dermatitis using risk reduction indices and estimated costs. The number needed to treat indicates that for every five cows treated with oxytetracycline bandages, a client prevents occurrence of one treatment failure compared with the ceftiofur management program. The simple cost accounting procedure suggests the cost of 5 oxytetracycline bandage treatments is $17 less than the cost of the treatment failure they prevented. Therefore the rational choice is to enact the oxytetracycline bandage treatment program.
†Data on costs from North Carolina State University, College of Veterinary Medicine, Veterinary Teaching Hospital Pharmacy, and a milk value of $26.45/L ($12/cwt).
‡Data on treatment efficacies from Guterbock WM, Borelli CL, Read DH: *Evaluation of four therapies of papillomatous digital dermatitis in dairy cattle.* Proceedings of the twenty-eighth annual meeting for the American Association of Bovine Practitioners, San Antonio, Tex., September 1995.
§Absolute risk reduction (ARR) = 0.26 − 0.06 = 0.20.
‖Relative risk reduction = ARR/0.26 = 0.20/0.26 = 0.77.
¶Number needed to treat = 1.0/ARR = 1.0/0.20 = 5.

on cotton balls under a duct tape bandage and left on for 7 days. All animals were evaluated at day 28 for clinical response (no pain, no lameness, and healed or healing lesions on inspection). The data in Table 2-10 indicate my estimates of treatment costs (medications, disposables, labor, and a conservative milk withdrawal for oxytetracycline), the published, statistically significant failure rates through 28 days, and the derived risk reduction values and NNT. The table also shows a short calculation to determine if it is worth recommending one protocol or the other.

The oxytetracycline bandage protocol, although almost costing half again more than the ceftiofur treatment ($32/$22 = 1.4) because of its higher success rate (94% [1.0 − 0.06] versus 74% [1.0 − 0.26]), more than recoups its added costs by preventing a case failure in at least one of five treated cows. In other words, according to this study and these cost estimates, by establishing an oxytetracycline bandage protocol for treatment of papillomatous digital dermatitis, the producer invests $48 to avoid spending $65. Here is yet another way to say it: every time the dairy treats five cows with the oxytetracycline bandage protocol, overall, the farm realizes a $17 savings over the ceftiofur protocol.

The risk reduction techniques allow an analyst to evaluate different timeframes of studies, to look at individual animal and herd-level choices, and to place the results into economically important terms. Readers wishing to further their knowledge in these techniques are encouraged to refer to Sackett et al (1991) for advanced uses of these methods.

Accounting for Uncertainty in Clinical Decisions: Decision Analysis

In a changing world choices are made without the full knowledge of their effects. Each choice opens some future options while closing off others. Control can be exercised over some events, such as in ordering a culture or prescribing a treatment. However, many events are beyond control: culture results are not known until they are run, and a herd's response to a treatment program is unknown until therapy is under way. Lastly, as mentioned in the "Likelihood Ratios and Figuring Out the 'Grey' Zones in Clinical Tests" section on clinical tests, the information that becomes available always must be evaluated for validity. Hence, uncertainty is a constant and undeniable part of practice.

Decisions must be made, in spite of the uncertainties. For the majority of choices in life, decisions can be made without much introspection. The decision may not be so important as to warrant analysis, or the outcomes may be so easy to rank that the choice is obvious. Occasionally, however, situations arise in which the consequences of a choice are not obviously apparent. At these times systematic methods are needed to estimate future events, consequences of actions, likelihoods of occurrences, and the end values of the many scenarios facing analysts. This is where a discussion of the tenets and methods of *decision analysis* proves of value. Clemen (1995), Sackett et al (1991), and Weinstein and Fineberg (1980) offer more in-depth explanations and explorations of the powerful techniques in this discipline.

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Function of Decision Analysis

Decision analysis techniques (DAT) help practitioners through the quagmire of uncertainty by formalizing the approach to a problem. In doing so, three characteristics of the process become apparent. First, DAT force analysts to be explicit in formulating a problem by its component parts—allowing the temporal quality of a diagnostic or therapeutic workup to be considered in detail, for instance—and by encouraging them to recognize the areas about which they are unsure. Second, DAT integrate quantitative knowledge into the process. The quantitative aspects come to the fore once the analyst has identified the uncertainties of the choices ahead. The algorithms used in DAT force analysts to make statements about probabilistic events, even if the estimates' precision is only with regards to how little is known about an event; it may be sufficient to simply get beyond terms such as "more likely" or "less apt to happen" and get evaluations of "50:50 chance" or "85% of the time." Practitioners are also prodded to seriously examine what kind of outcomes they will be experiencing, and how they (and the client) will value differing outcomes. Third, and this is why DAT can be of such value, the end result is a system-level view that allows decisions of known strength; it allows analysts to prescribe a course of action from among the many available choices. It accomplishes this because the explicitness and quantitative nature of the process allow the analyst to work with the entire problem without losing sight of the details within that system; it forces a look at the entire picture, yet not to the exclusion of its component parts. Decision analysis also promotes consideration and evaluation of the relationship between the information-gathering process and decisions that will need to be made based on that information, so it is helpful in setting up timelines for larger projects.

Decision Analysis Step 1: Identify and Bound the Decision Problem. At times the most difficult part of the process is defining the problem at hand. What, truly, is the problem being faced? Is a respiratory disease outbreak in feedlot steers a problem with nutrition, shipping, processing, purchasing choices, handling, or some combination of all these factors? In an outbreak situation this requires practitioners to carefully identify what a "case" truly is so that findings are not confounded with inappropriate data. In a herd production problem this means establishing thresholds for production indices that differentiate between normal and abnormal. In some situations a clinical state definition may be complete with "sick" and "normal." However, other situations may call for more refined categories such as "full recovery," "partial recovery," "recovered but relapsed," "no recovery," and "death." Other considerations, such as any prognostic value of tests for herd-level decisions, animal welfare, and regulatory limits, can play a role in determining the final choices made.

Decision Analysis Step 2: Structure the Decision Problem (Decision Trees or Decision Diagrams). In structuring a decision problem, analysts aim to keep the different types and timing of events in proper sequence. In the process of evaluating complex decisions, each contingent on information available at that specific time, a "road-map" of decision flows can be formed, often in the form of a *decision tree*. The illustration of the decision tree in Fig. 2-26 displays the three basic parts of any decision diagram, by using an example adapted from a study evaluating the financial and legal outcomes of antimicrobial testing strategies in dairies (Slenning and Gardner, 1997). By convention, decision flow diagrams are read from left to right. The first point to note is that they branch at each alternate action or chance event, making a winding trail of the sequential events that compose one potential *path*. Second, the tree explicitly lists each event in the process, forcing the analyst to consider the uncertainty (i.e., to establish probabilities for uncertain events) inherent in the choices. Third, it quantifiably describes the outcome values the analyst placed on the endpoints of the different branches, again, forcing an evaluation of the outcomes and the best means of achieving, or prescription for attaining, a given desired outcome.

The decision tree in Fig. 2-26 could be "read" as follows. The decision point being addressed is the question inside the *decision node:* whether to test cows following a set withdrawal period for milk residues of penicillin G (the "square"). If the producer decides to test, the path followed is the one leading up from the decision node (with the "yes" description) to the first *chance node* (chance nodes are signified by "ovals"). This node states there is some probability the cow in question will test positive for antimicrobics. Note this is not claiming that the cow actually is violative, only that the on-farm test has called her positive. This node has two paths emanating from it: one for the chance result that the cow tests positive, and the other for the chance result she does not. Given this test result, the producer will not ship the milk. However, there is some chance that the test is a false-positive test, given the testing technology's ability to identify drug concentrations well below the legal thresholds (Gardner et al, 1996). This possibility is illustrated by the next chance node in the path (the path continuing up and to the right), where the cow is assigned to either a true-positive or a false-positive categorization (the "yes" and "no" descriptors following the "≥10 ppb" chance node at the tree's upper right). Note no decision is made here; the test result of "positive" has determined that all such milk, whether classified correctly or not, will not be shipped for human consumption.

Should the producer decide not to test the cow for antimicrobic residues (the path leading down from the decision node with the "no" description), the first chance event is whether the cow actually has violative levels of penicillin. From there is a set of potentially two more chance events, each describing a testing point performed by the milk processor at the level of the milk truck ("Tanker pos") and the dairy's own bulk tank ("BulkT pos"). If the tests are not positive, the milk goes into the human consumption chain. If the test is positive, however, the dairy is traced back and suffers financial, legal, and regulatory consequences of shipping violative milk. Note that the path in which the cow tests negative at the farm level is a stepwise replica of the do-not-test path just described. However, the probabilities for violations are different between the two paths.

Decision Analysis Step 3: Select Decision Criteria. Different analysts choose different criteria for selecting one alternative versus another. It may be fairly clear: one option may offer higher incomes than another (i.e., the decision is to take the maximum incomes) or a certain path might offer less variability (i.e., the decision is to minimize risk) in outcomes. In situations in which an outcome's value is difficult to assess, the decision could be made on the basis of time to conclusion or efficiency of resource utilization (as shown in the previous discussion of screening and diagnostic testing strategies). Or, as in the B:C analysis example, there is no reason why an analyst cannot select a portfolio of several decision criteria and make the decision based on the package results from the portfolio. The important point is to make the choice of decision criteria *before* running the actual analysis. Otherwise it becomes difficult to avoid choosing the criterion that best fits the analyst's or producer's preconceived "favored option."

Decision Analysis Step 4: Choose the Best Course of Action. For most decision analysis problems, this step is the easiest. The analyst merely regularly applies the decision

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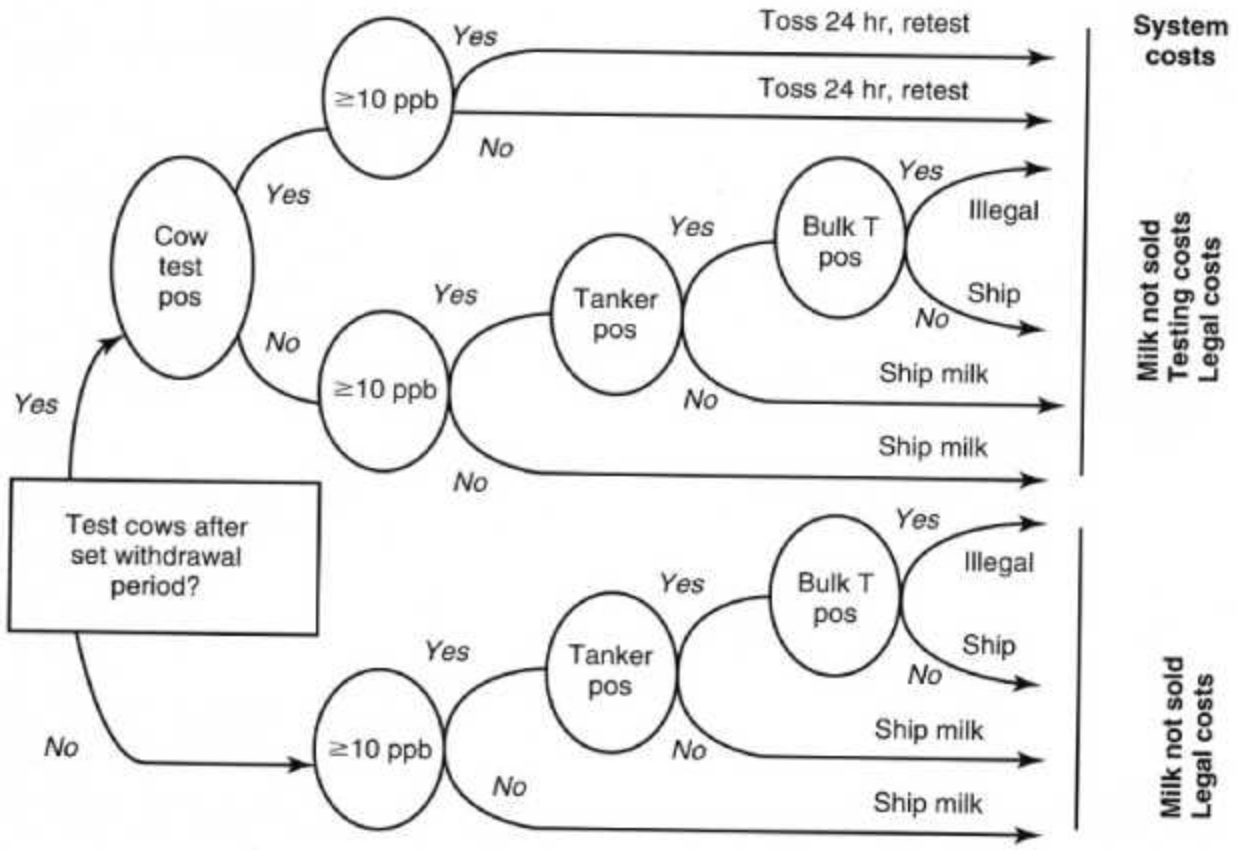

FIG. 2-26 Outline of decision tree investigating the decision to test dairy cows for beta-lactam antimicrobic (penicillin G) residues following a given withdrawal period. The "Test cows after set withdrawal period?" box is the actual decision being addressed. Ovals represent chance nodes–events over which practitioners have no control–for which probability statements must be devised for each path leading from there. Rectangles represent decision nodes. *≥10 ppb,* Antimicrobic concentration is greater than or equal to 10 parts per billion (U.S. tolerance level for penicillin G residues); *pos,* test result is positive for antimicrobic; *Tanker,* milk tanker truck; *BulkT,* on-farm milk bulk tank; *Illegal,* milk shipment is stopped and legal proceedings are enacted; *Ship,* milk is shipped without being detected as violative. (From Slenning BD, Gardner EA: *J Am Vet Med Assoc* 211:419-427, 1997.)

criteria chosen for the problem to each step in the problem, working in reverse chronological order. For decision tree analysis, two algorithms are applied to different paths, depending on the nature of the node immediately giving rise to the path.

For example, in the decision tree illustrated in Fig. 2-26, the solution could begin with the analyst evaluating the endpoint at the upper right where the producer has decided to not ship milk from test-positive cows. Tracing backwards from that endpoint, the analyst can find the first node is a chance node ("≥10 ppb") which has another path emanating from it. The two paths represent the cow being withheld when her milk is truly violative, and the other possibility that she is incorrectly withheld because of a false-positive test result. When a chance node gives rise to a set of paths, the algorithm used is called *averaging out* and requires the analyst to take the probability of each outcome and multiply it by the endpoint's value. The analyst does the same for each path leaving the chance node and finally sums the products of each path's multiplication. This sum is termed the *expected monetary value (EMV)* of the node. In this way the chance node is assigned a weighted value; it is weighted for both the likelihood of each endpoint's occurrence (the probabilities) and its magnitude (the actual endpoint values).

Should the reverse chronology process bring the analyst to a decision node, a different algorithm is used. Remember, at a decision node the practitioner actually controls which path will be followed. Unlike a chance node, in which the outcomes cannot be controlled (and therefore an averaged result is created by "averaging out"), with decision nodes the analyst chooses the path that best meets the decision criteria and disregards the suboptimal paths. This process is called *folding back* or "pruning" the tree.

Once the decision-maker backs up to the original decision and makes the final "fold back," the resulting set of paths left describes the optimal course of action, according to the established decision criteria and values entered into the tree.

Decision Analysis Step 5: Perform Sensitivity Analysis on "Soft" Values. As in the example of the partial budget exercise on intensive grazing of a cow-calf herd (Figs. 2-23 and 2-24), the final step is to review the inputs to the decision and perform a sensitivity analysis of the decision on those values and probabilities that are least certain. This is done by changing one or more inputs over a reasonable range of values and solving the tree for each combination. The set of solutions that is generated this way will be able to establish the range of inputs over which the decision is stable (that is, over which the decision will still be the correct decision).

Walking Through a Practical Example of Decision Tree Analysis

Introduction to the Adjunct Use of Oral Calcium Gels Following Successful Treatment of Hypocalcemia

In 1997 Oetzel et al produced a clinical trial in which they evaluated the feasibility of using oral calcium gels as adjunct therapy for cows who had been down previously and successfully treated with intravenous calcium solutions. In short, the trial used 70 cows with clinical hypocalcemia that had been successfully treated with intravenous calcium. This

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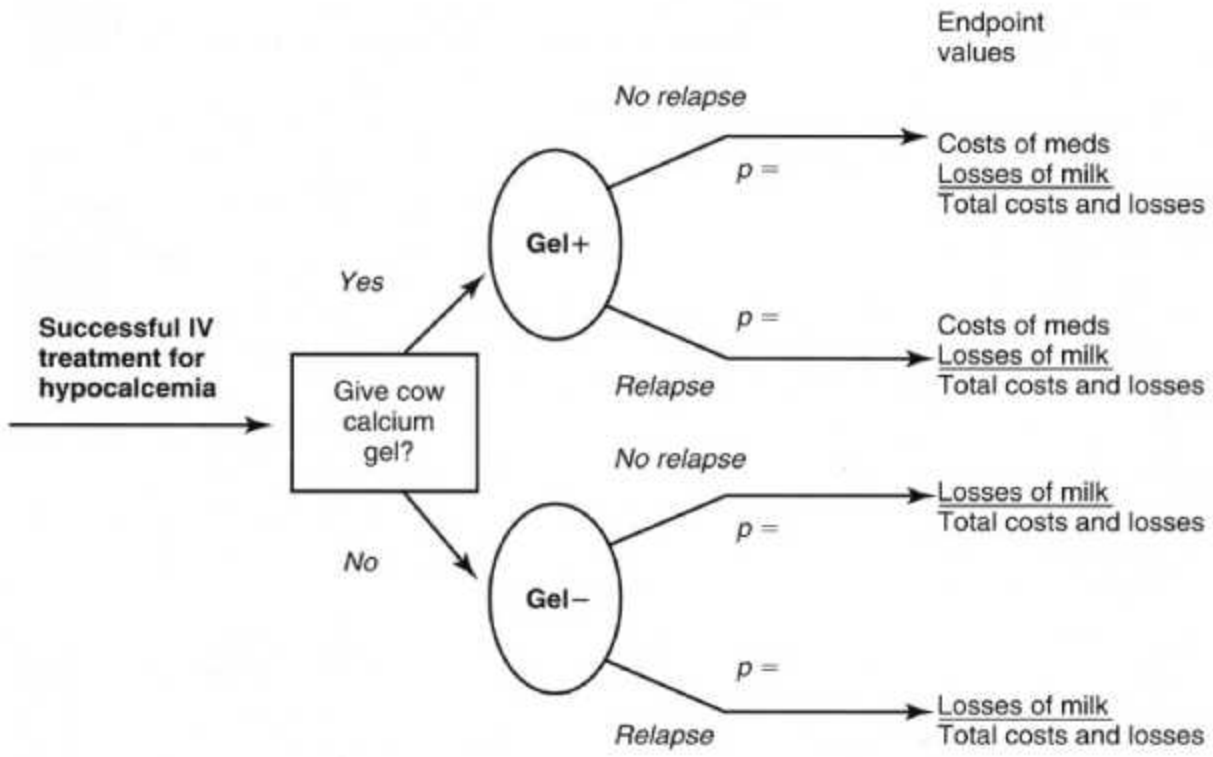

FIG. 2-27 Decision tree to evaluate the choice of using oral calcium gel as adjunct therapy following successful treatment for the initial hypocalcemic event. Values for endpoints and probabilities have not been entered.

population was randomly allocated to two groups: the treated group (n = 31), in which the cows were given two doses of a commercially available calcium chloride gel upon rising, and the control group (n = 39), in which the cows were given two doses of a placebo gel upon rising. The cows were followed for relapse, which was defined as a clinical inability to rise. The basic results were that 4 of the 31 treated animals (13%) relapsed, whereas 14 of the 39 control animals (36%) relapsed. This difference was significant at the 5% level. Hence, it appeared that use of calcium gels following intravenous calcium treatment for hypocalcemia was clinically useful. But was it useful enough to warrant incorporating its use in a dairy's protocol for treating milk fever cases? This is a good exercise to pull together topics from the economics section of this chapter as well as to close off this decision analysis section.

Decision Analysis Step 1: Identify and Bound the Problem. In the current instance, this step is fairly straightforward. The analyst is asking whether oral calcium gels should be instituted in the protocol for working with initially successful hypocalcemia cases, with the aim to reduce relapses. Hence the problem deals only with successfully treated animals and only looks to outcomes of either relapsing or not. It will have, therefore, one decision node (use the calcium gel) with two paths leading from it ("yes," use the gels; "no," do not use the gels) and chance nodes for both parts of that choice ("does the cow relapse after using the gel?"; "does the cow relapse after not using the gel?"). It does not address issues of nutrition (important to affect overall hypocalcemia rates) or other peripartum diseases and management.

Decision Analysis Step 2: Structure the Decision Problem. Fig. 2-27 illustrates the complete decision tree for this problem, except it has no values or probabilities in place. They are listed, but the values themselves have not been identified or defined. It follows the description just given: one decision node, two paths from that node, a chance node at each of those paths, and a yes-no set of paths leading from each chance node. It indicates that the endpoint values for each unique pathway will combine the medical costs to get the animals to that point and the estimate of the milk losses incurred by the animals continuing to be in suboptimal health. Note also that the probabilities, because each chance node has only two possible outcomes (relapses or not), require the analyst to specify only the probability of relapse following treatment or relapse without treatment. The other outcome must be the difference formed by subtracting the first probability from 1.0; the probabilities from any chance node must sum to 1.0 because otherwise not everything that could occur is described.

The probabilities come from the research trial itself. The trial found a 13% relapse rate in the treated group and a 36% relapse rate in the control group. Hence, those are the relapse rates to place in the decision tree. The opposing rates (no relapse) will, as mentioned above, be 1 − (relevant relapse rate), or 87% for the treated group and 64% for the control group.

Calculating the endpoint values is more complicated. The reader probably already realizes that each endpoint entails its own unique partial budget that compares changes in revenues and costs. Since minimizing costs following a disease event is being examined here, all the entries in the partial budget can be described in terms of costs (i.e., no revenue enhancement is involved). Fig. 2-28 lists the entries and shows the simple cost accounting that meets the current needs. The assumption has been made that having gone through a hypocalcemic event will lower later lactation milk production. The choices made here were for a 14% loss in total lactation milk production (expressed in terms of 305-day fat corrected milk) for cows that relapse; half that loss for cows who do not relapse but are not given the calcium gel and, therefore, still undergo subclinical losses; and a 3% loss for those who do get the gel and who also do not relapse.

Decision Analysis Step 3: Select the Decision Criteria. As the analyst is looking at costs, the rational choice is to select the course of action with the lowest costs, as demonstrated by comparing the EMVs of the two chance nodes ("Gel+" versus "Gel−"). Were the analyst looking at revenues, the rational choice would be to select the chance node with the highest EMV.

Decision Analysis Step 4: Choose the Best Course of Action. The analyst first starts at the endpoint designated by the path that ends with the "Gel+" chance node's "No re-

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	A	B	C	D	E	F	G	H
1	**A. We need to establish costs**							
2								
3		Assumed costs				Individual	Cost per	
4						cost	treatment	
5		Calcium chloride gel costs				($6)	($12)	
6		Relapse costs of additional Rx					($40)	
7		Relapse losses		14.0%	of 20K 305FCM		($392)	
8		No relapse (without treatment)		7.0%	of 20K 305FCM		($196)	
9		No relapse (with treatment)		3.5%	of 20K 305FCM		($98)	
10		Milk sells for:					$14	
11								
12	**B. We need to build partial budgets**							
13								
14				Gel+		Gel−		
15				Relapse −	Relapse +	Relapse −	Relapse +	
16		Calcium chloride gel		($12)	($12)			
17		Added cost via relapse			($40)		($40)	
18		Milk loss via relapse			($392)		($392)	
19		Milk loss via no relapse of gel−				($196)		
20		Milk loss via no relapse if gel+		($98)				
21		Total losses, by treatment choice		($110)	($444)	($196)	($432)	
22								

FIG. 2-28 Spreadsheet-based depiction of estimated costs for the calcium gel decision tree (Fig. 2-27). Cost estimates in section A are from local market prices at the time of writing. The problem assumes some subclinical effect of hypocalcemia, hence the losses suffered for all groups. However, the treated/no relapse group has the least loss (3.5%) over a lactation, the cow that relapses has the greatest loss (14%), and the control/no relapse cow has a midlevel loss (7%). Section B calculates the costs for each of the four unique endpoints, according to the information in section A. Negative values are shown in parentheses. *FCM,* Fat corrected milk. (Data adapted from Olson JD: Health and reproductive aspects of the peripartum cow. National Dairy Database website. Available at: http://www.inform.umd.edu/EdRes/Topic/AgrEnv/ndd/health/HEALTH_AND_REPRODUCTIVE_ASPECTS_OF_THE_PERIPARTUM_COW.html. Accessed August 30, 2000.)

lapse" potential, the path ending at the upper right of Fig. 2-27. Fig. 2-28 shows that this node has an endpoint value of ($110); note that parentheses are a commonly used means of indicating negative financial values. Based on the original data, there is an 87% ([31 − 4]/31) probability of this occurring. If this path is traced backward in time to its node, the analyst finds that it has one accompanying path (the "Relapse" path). From Fig. 2-28 this path has a probability of occurring of 13% (1 − 0.87 = 0.13) and an endpoint value of ($444). Since the paths are connected by a chance node, the "averaging out" algorithm is followed. Hence, the EMV of the "Gel+" chance node is generated by multiplying each path's probability against its endpoint value and summing them. This is accomplished as follows:

$$EMV_{GEL+} = [\text{Endpoint Value}_{\text{PATH ONE}} \times \text{Probability}_{\text{PATH ONE}}] + [\text{Endpoint Value}_{\text{PATH TWO}} \times \text{Probability}_{\text{PATH TWO}}]$$

$$EMV_{GEL+} = [(\$110) \times 0.87] + [(\$444) \times 0.13]$$

$$EMV_{GEL+} = (\$153)$$

Had three or more paths been emanating from the chance node, the same process would have been followed: multiply each endpoint value times its probability and sum them all. The exercise for generating the EMV of the "Gel−" chance node is accomplished by combining data from Fig. 2-28 in a similar manner:

$$EMV_{GEL-} = [\text{Endpoint Value}_{\text{PATH ONE}} \times \text{Probability}_{\text{PATH ONE}}] + [\text{Endpoint Value}_{\text{PATH TWO}} \times \text{Probability}_{\text{PATH TWO}}]$$

$$EMV_{GEL-} = [(\$196) \times 0.64] + [(\$432) \times 0.36]$$

$$EMV_{GEL-} = (\$281)$$

The final decision tree, with solution, is shown in Fig. 2-29. The EMVs have been calculated as just described. Since the decision criterion chosen in the "Decision analysis step 3" section is to select the course of action with the lowest costs, as demonstrated by comparing the EMVs of the two chance nodes ("Gel+" versus "Gel−"), the analyst chooses to go with the option of the "Gel+" node. The "fold back" algorithm is performed, and the "Gel−" path is dispensed with as being suboptimal. This is signified by using standard DAT symbols, the double line crossing the path leading from the decision node to the "Gel−" chance node.

Decision Analysis Step 5: Perform Sensitivity Analysis on "Soft" Values. Several values may be in question regarding this problem. One such issue deals with the failure rates found in the Oetzel study. What if they were different? How different could the experience be and still have the treatment be optimal? To do this the probability for relapse is simply changed and the EMVs recalculated. This is shown in Fig. 2-30, in which the EMV for each group has been calculated over the range of potential failure rates (i.e., relapse rates), from no failure to 100% failure.

One way to interpret Fig. 2-30 is to determine equivalent EMVs at differing failure rates. For instance, suppose the analyst felt the relapse rate found in the study for the control (e.g., Gel−) group (36%) was reasonable but doubted the claimed relapse rate for the treated animals (13%). Perhaps the analyst's experience with the calcium gel was not as good. How high could the treated group's relapse rate be and still remain the right choice of action? To do this the analyst merely identifies the point on the control EMV line that signifies the 36% relapse rate and draws a horizontal line

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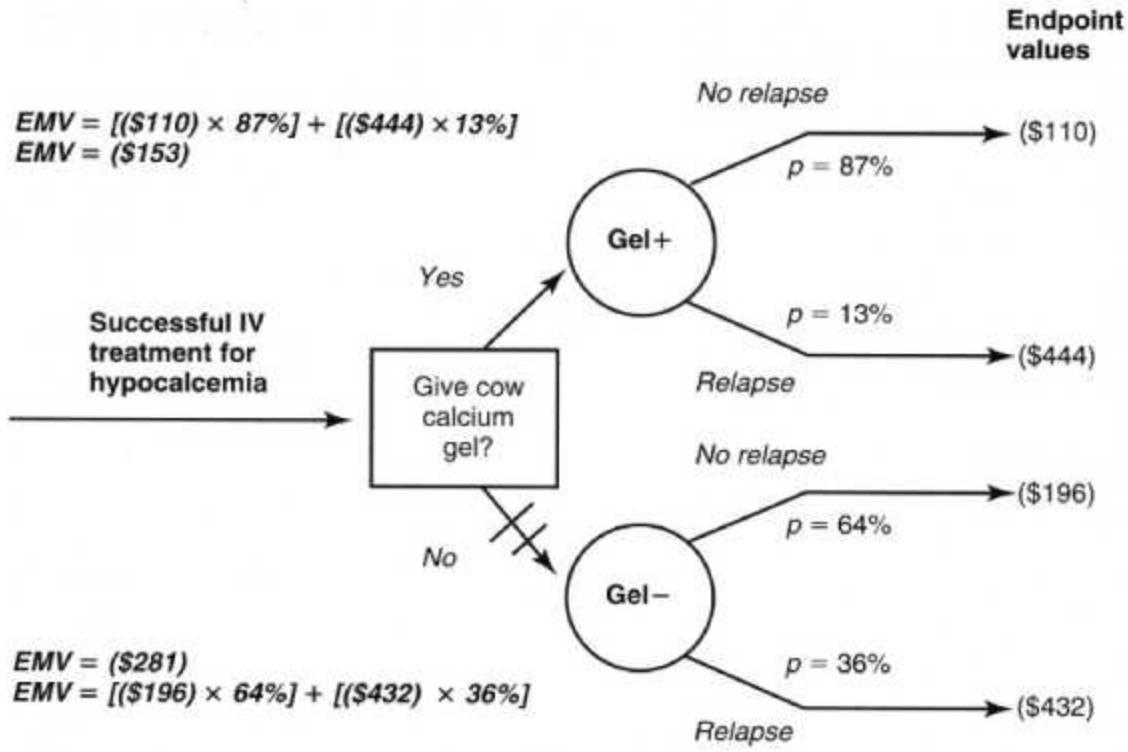

FIG. 2-29 Completion of the decision tree evaluating the choice of using oral calcium gel as adjunct therapy following successful treatment for the initial hypocalcemic event. The endpoint values and probabilities were taken from Fig. 2-28. The expected monetary value *(EMV)* for the two chance nodes were generated by following the "average out" algorithm. The rational choice is to select the option with the lowest EMV. This is the "Gel+" path at ($153). The analyst dispenses with the other option by drawing a double line across that path. The optimal path, when faced with a cow successfully treated with IV calcium, from this decision tree, is to treat the cow with calcium gel.

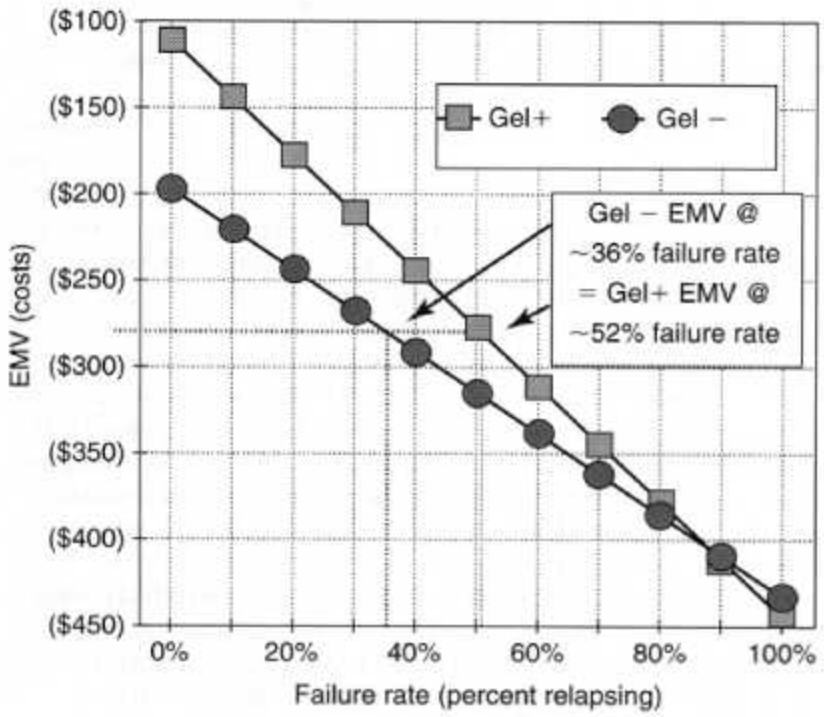

FIG. 2-30 Sensitivity analysis of the calcium gel decision to failure rate for both the treated and the control groups. The graph indicates that at the foundation study's control failure rate of 36%, the treatment group could have a failure rate of over 50% and display an equivalent expected monetary value *(EMV)*. It also suggests that even if the control group had a 0% failure rate, the treated group could suffer up to approximately a 25% failure rate and still be the optimal choice (i.e., the EMV of control at 0% failure rate is approximately equal to the EMV of treatment at between 25% and 30% failure rate).

from the y-axis across that point and continues the line to the treated EMV line. Then the analyst drops a vertical line from the intersection of the horizontal line and the treated group EMV line and reads where it intersects the x-axis. Doing this, with the relations shown in Fig. 2-30, suggests that the treated group could suffer a relapse rate of nearly 52% before its EMV drops below that of the control group. Another way of saying this would be to identify a treatment relapse rate of approximately 52% as being the "indifference" relapse rate, since at that point the analyst would be indifferent to either treating or not treating with the calcium gel. Since the study's relapse rate was approximately one fourth the magnitude of the indifference level, the analyst can claim that this decision is stable with regard to failure rates.

The most glaring assumptions in this model surround the relationship of long-term milk production losses relative to relapses, to nonrelapsed animals treated with calcium gel, and to nonrelapsed animals not treated with calcium gel (Fig. 2-28). A sensitivity analysis is certainly called for to evaluate the effect of changes in that set of assumptions. One question might address the costs of treating relapses. The relative magnitudes of loss (i.e., that the loss for a full relapse is approximately twice the loss of a nontreated, nonrelapsing cow, which itself is about twice the loss for a treated, nonrelapsing cow) could be another point of contention. One way to look at this issue is to keep the relative magnitudes the same but to alter the relapse losses down to no loss. With no loss, then, none of the animals would show long-term effects of hypocalcemia. Both issues—the cost of treatment and long-term losses—are illustrated in Fig. 2-31.

In Fig. 2-31 the analyst is looking at a two-way sensitivity analysis and evaluating the effects of changes in relapse rates and the effects of changing the cost of treating a relapsed case. The measure being used is the difference between the two groups' EMVs, such that a positive difference indicates that, for the given combination of relapse rate and relapse treatment costs, the EMV of the treated group was greater than that for the control group—and the gel treatment is the best choice. If the EMV difference is negative, not treating with the calcium gel is optimal. The first thing to note is that if the medical costs incurred in treating a relapsed case exceed approximately $50, the calcium gel therapy is optimal,

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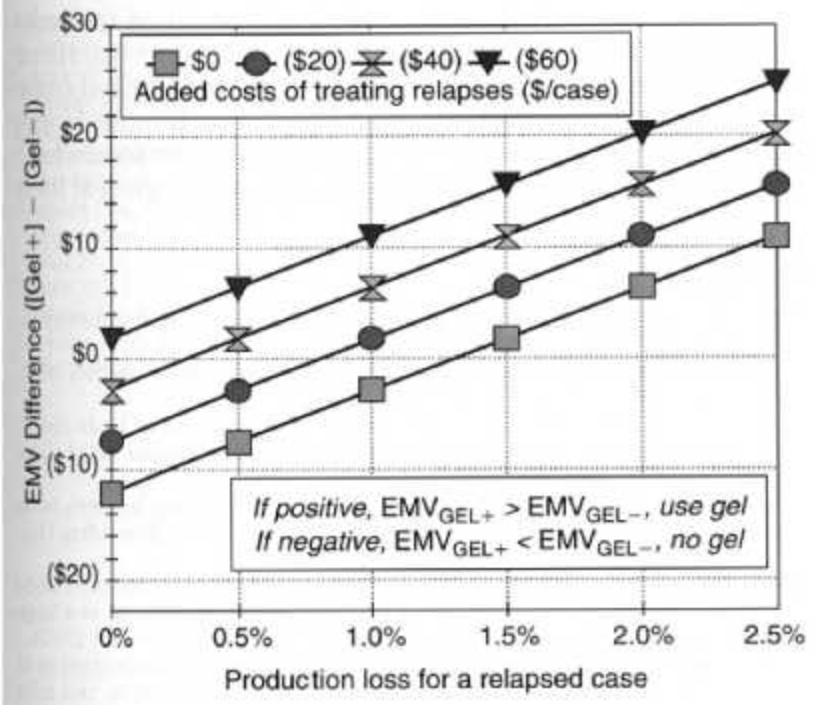

FIG. 2-31 Illustration of a two-way sensitivity analysis for the calcium gel decision problem. Estimated monetary value (EMV) difference changes ($EMV_{GEL+} - EMV_{GEL-}$) are being evaluated with regards to the actual medical costs of treating a relapsed cow (range from $0 to $60) over expected production losses for a relapsed case (range from 0% to 2.5%). If relapsed cows showed no decrease in production, medical costs of treating a relapsed case would need to exceed $40 to make the calcium gel preventive therapy cost effective (between a treatment cost of $40 and $60, the 0% production loss situation switches to a positive EMV difference). However, if a relapsed animal suffers a production loss equal to or above 1.5%, even if no extra costs were incurred in treating a relapsed animal, the calcium gel treatment is optimal (the $0 medical cost line crosses the $0 EMV difference threshold between 1.0% and 1.5% production loss). Hence the choice to use the calcium gel appears stable relative to changes in treatment costs and long-term losses.

regardless of whether any production loss results from the relapse. Note also that if a relapsed cow suffers more than approximately a 1.25% production loss, the gel therapy is again optimal, regardless of the cost of treating a relapsed animal. Since it is difficult to support a claim that relapsed cases will have little or no long-term effects, the analyst can also declare the decision to use the calcium gel as being fairly robust against estimates of long-term effects.

With the use of the basic decision tree, along with a one-way and a two-way sensitivity analysis, a general statement can be made:

Assuming the study's relapse rates approximate reality for a given client, treating all posttherapy hypocalcemic cows with oral calcium gel appears to be the economically rational choice within reasonable levels of failure rates (i.e., any treatment relapse rate of less than 50%), treatment costs (i.e., if treating a relapsed cow incurs approximately $60 in extra costs, and no long-term effect can be claimed), and long-term loss estimates (i.e., if long-term losses are at least 1.5% over a lactation).

The value of being able to make such a general statement is that it frees the analyst from having to prove costs or success rates or other inputs to a narrow range. For instance, if a client feels that the calcium gel therapy will not keep relapse rates at 13%, as found in the study, the calcium gel therapy is still optimal as long as the client's experience is that untreated animals relapse in about one third of cases and that the treated animals relapse at less than a 1 in 2 rate. It will not have as great a monetary advantage over not treating at a 40% failure rate, but it will still have the advantage.

READING THE LITERATURE ON ECONOMICS OF ANIMAL DISEASES AND CONTROL PROGRAMS

Literature abounds with reports on the costs of disease and disease control programs. Some are quite good, offering useful information and comparisons for decision-makers. Others are incomplete, only hinting at total costs. Still others are covertly misleading, having been built on preconceived notions.

Some hints at evaluating such literature follow. When reading a paper relating to the economic evaluation of a disease, there are several questions to keep in mind:

1. Is the study (or the several studies) on which the economic analysis is based *valid, both scientifically and clinically*? If the paper addresses the B:C of a new treatment versus an older treatment, are the differences described statistically significant? Do the results make sense in biological, medical, or epidemiological terms? If the underlying science is inappropriate, no amount of economic expertise will salvage the results.

2. What *kind of analysis* is being portrayed? Is it a partial budget, marginal analysis, decision analysis, capital budget, simulation, or some combination thereof? Is it based on a clinical trial, a model, or a retrospective study? The type of analysis used brings with it certain advantages and disadvantages, as discussed previously. None are perfect, but the reader still needs to know what to consider.

3. Recognizing that no analysis is ever complete, does the study *include areas of major importance, or at least acknowledge important areas omitted*? This can be looked at in two ways:

- *Does the study account for important items* for the particular area, industry, and time it considers? If so, does it also account for important items for the particular area, industry, and time about which *the analyst* and the client(s) are concerned?
- *From whose viewpoint does the study address costs and benefits?* Some studies evaluate a system from the social or governmental point of view. In such cases, benefits accruing to the public are considered true benefits, whereas costs assumed by producers may not be considered program costs (Hanson and Hanson, 1983). Farmers might disagree with this.

4. Does the analysis conclude with *some recommendation for action or behavior change?* Does it shed light on how to solve a problem? This should not be misinterpreted; a simple "this is what happened" type of report is often useful, in and of itself. However, without also proposing solutions it is difficult to see which problems the authors thought to be amenable, and hence, where the options for addressing those problems lay.

A recommendation may be the least important of the criteria, for what an author sees as an option may or may not be applicable to the reader's situation. However, if proposed solutions are included, they give the reader another means of understanding the system being evaluated.

5. What *assumptions* have been made? This can be tricky. The baseline from which the analysis starts must be carefully identified: is the comparison or foundation disease model or herd setting assumed to be perfect (i.e., no diseases of any kind), optimal (i.e., as good as it can get), or average (i.e., about what to expect for most producers). The "perfect" baseline inflates the relative costs of any disease and hence exaggerates the value of controlling that disease. For the "average" comparison, the analyst will underestimate the value of controlling the problem under study if the client is better than average.

Many assumptions are not stated; they are *implicit*, not *explicit*. For example, when the practitioner assumes a constant herd size, he or she is also assuming that this is a reasonable,

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or maybe even optimal, situation. In a way, it is assuming the industry cannot take the decreases in income resulting from shrinking herd sizes, or that increases in herd size are equally unacceptable. This assumption may limit the number of options available, because it removes any management strategy from the decision that might alter herd size.

6. How sensitive will the recommendation be to the assumptions made? *Sensitivity analysis* for the "softer" numbers and assumptions always should be addressed. If not, the reader should be careful with how widely the results are referred. Just because something made it into a publication and therefore got wide distribution does not mean the results are applicable across a wide audience.

7. Have long-term financial flows been *standardized using present value concepts?* If so, what kinds of discount rates are used? Are they appropriate? Are they overly low or high and therefore inordinately favoring of certain types of cash flows? If they are not used, do the data allow the outcomes to be converted using time value of money techniques? In a similar vein, if the study evaluates results over years, the study should use *"constant" costs and returns*. Often an author will say something to the effect of the following: "...Financial information was converted into constant 1997 values...." This allows the research to dampen the effects of inflation, currency exchange rates, recessions, and other macroeconomic effects, upon the outcomes.

8. If the report describes gains and losses, does it present the *biological effects separately from the economic effects?* The economic effects may change as markets change. In the United States during the late 1980s, day-old Holstein bull calves were selling for $5 to $10. Within 5 years they were selling for $125 to $150, a reflection of the interest in dairy beef and of a general upswing in the cattle market. Certainly a project to protect such calves from neonatal diarrheas would look much more favorable economically when bull calf values were high, just from the differences in the market. The biological effects should form the basis for modifying the analysis for future market conditions. Without biological data, a study's findings cannot be adjusted to changes in markets and finance.

Interested readers are encouraged to refer to Greenhalgh (1997) for a more in-depth discussion on critical review of the medical economic literature.

CONCLUSION

This chapter touches on just some of the most powerful analytical tools available to the production medicine practitioner. From reading the chapter and working through its examples, the reader should be able to perform the following:

- Evaluate data with regards to its type and distribution
- Understand and develop basic epidemiological rates, proportions, and ratios from personal clinical experiences
- Differentiate between those differences and associations that are important and those that are spurious
- Interpret diagnostic tests, whether on an individual or group basis
- Design diagnostic and treatment programs using clinical test efficiencies
- Work with financiers and producers on economic issues of markets, production, and time value of money
- Establish and analyze partial budgets, B:C analyses, and decision analysis systems

Additionally, if the reader turns back to the start of this chapter and the hypothetical questions a client might ask a modern production veterinarian, the contents just completed should allow the practitioner to know what type of information and what kind of analysis are needed to address those concerns.

Will a conscientious reader be good at all of the techniques mentioned just from reading the chapter? No. He or she will be just starting. Some readers may never need some of these techniques, and others will need much more. Hopefully both types of reader, and the many who fit somewhere in between, have been given the guidance to progress at their own speed.

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APPENDIX A

STATISTICAL TEST VALUES FOR Z-TESTS AND CHI-SQUARE TESTS

CONFIDENCE	50%	60%	70%	80%	90%	95%	99%
Z-test*	0.68	0.84	1.04	1.28	1.64	1.96	2.57
Chi-square†	0.45	0.71	1.07	1.64	2.71	3.84	6.63

*Listed Z scores are for a two-tailed test; the analyst is testing whether the value in question are different, not whether one is bigger, better, higher, etc. than the other.
†Chi-square statistic values are exclusive for a 2 × 2 table (i.e., a test with 1 degree of freedom; no. of degrees of freedom = [no. of rows − 1] × [no. of columns − 1]). Larger tables (i.e., 2 × 3, 3 × 4) require a different set of chi-square statistic values.

EXAMPLES:

A *Z-test* value of 1.17 is calculated. This yields a statistical confidence between 70% and 80% (i.e., *P* is between .20 and .30) that the observed difference is real.

A *chi-square test* value of 4.46 yields a statistical confidence level between 95% and 99% (i.e., *P* is between .01 and .05) that the observed difference is real.

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APPENDIX B: H.O.T. STATS WORKSHEET 1

Z-TEST CONFIDENCE INTERVAL FOR THE DIFFERENCE BETWEEN TWO MEANS

I. **DATA.** A practitioner is looking as heifer weights, both pregnant and open, to see if a difference exists between the two groups. The following counts, mean weights, and standard deviations are found by using a calculator:

	Open	Pregnant
Count	15	22
Mean weight	667	676
SD weight	18	22

II. **INTERVAL STATISTIC.**

$(\text{mean1} - \text{mean2}) \pm Z_{score} \times \text{SQRT}\,[(\text{SD1})^2/\text{count1} + (\text{SD2})^2/\text{count2}]$

Where: meanX = Average of group X
Z_{score} = Z score value from a statistics table
SQRT = Square root function
SDX = Standard deviation of group X
countX = Number of animals in group X

Which, for this example, would be:

$(667 - 676) \pm Z_{score} \times \text{SQRT}\,[(18)^2/15 + (22)^2/22]$

III. **Z SCORES.** Z scores for the following levels of confidence (from any statistics text, or see Chapter Appendix A):

80%: 1.28 **90%:** 1.64 **95%:** 1.96

IV. **DO THE MATH.** Calculate the confidence intervals for the difference between means:

80%: −17.5 to −0.5 **90%:** −19.8 to 1.8 **95%:** −21.9 to 3.9

V. **DECISION RULE.** A confidence interval shows the likely range of the true difference in mean values between the two groups; if all the herd's open and pregnant heifers are captured (or were sampled numerous times), this is where their average weight differences would lie.

The *decision rule* is to reject the conclusion that a difference exists if 0.0 is captured in the range. There is 80% confidence that the nonpregnant group weighs somewhere between 17.5 lb to 0.5 lb less than the pregnant heifers. Note that to be 90% confident that the true mean difference was captured, the practitioner would need to admit that, given this sample size and the variability in the data, the pregnant group could actually be *lighter* that the open group by 1.8 lb—which does not fit the initial hypothesis. Hence, the practitioner cannot be 90% certain that the nonpregnant group is lighter than the open group. The same is true, of course, for the 95% confidence interval: It contains zero, so the practitioner cannot be 95% certain an actual difference is present.

Therefore the practitioner can be at least 80% confident that the apparent weight difference is real. Given that the range for the 80% confidence interval almost hits zero, the practitioner cannot be much more confident than 80%. Statistical theory does not tell whether 80% confidence is sufficiently certain to warrant action. That is the job of nonstatistical processes. But now we know just how certain we are.

Caveats

The Z-test confidence interval assumes a fairly normally distributed set of data. It is important to realize that this is usually true for differences between means of skewed data. It also assumes the samples being compared were selected at random from the overall population. If these do not apply, it means that you must be more careful in interpreting the results.

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APPENDIX C: H.O.T. STATS WORKSHEET 2

CHI-SQUARE TEST FOR CONTINGENCY TABLES

I. DATA. A practitioner has finished doing fertility work on a dairy and has the impression that fresh heifers do not "clean up" as well as fresh cows. The following 2 × 2 table shows the results of the examination. The italicized letters identify dells used in the next step.

	Clean	Metritis	Total
Heifers	15 *(a)*	12 *(b)*	27
Cows	42 *(c)*	16 *(d)*	58
Total	57	28	85

II. TEST STATISTIC. The equation for calculating the chi-square test statistic, using the letter identification with the table above:

$$\frac{[(a \times d) - (c \times b)]^2 \times \text{TOTAL}}{(a + b) \times (c + d) \times (b + d) \times (a + c)}$$

III. CHI-SQUARE VALUES. Chi-square values for different levels of confidence (from any statistics text [chi-square, 1 degree of freedom], or from Chapter Appendix A)

80%: 1.64 **90%:** 2.70 **95%:** 3.84

IV. DO THE MATH. Plug in the cell values and solve.

$$\frac{[(15 \times 16) - (42 \times 12)]^2 \times 85}{27 \times 58 \times 28 \times 57} = 2.37$$

V. DECISION RULE. If the test statistic exceeds the value of the chi-square at a given confidence level, the *decision rule* is to accept the idea that an association between the row and column factors exists at that level of confidence. Since the test chi-square at 2.37 is greater than an 80% confidence level chi-square value (1.64), but is below the 90% confidence level chi-square value (2.70), the practitioner is between 80% and 90% certain that an association exists between metritis and being a heifer. Heifers performed worse than the cows.

Caveats

As long as no cell in a 2 × 2 table has a value less than 5, and as long as the groups are independent and mutually exclusive, the chi-square for contingency tables is a very robust and easy method of determining statistical significance in data sets. In other words, this cannot be used for "before-after" comparisons on the same animals (not independent) or in situations in which the classification is not clear (not mutually exclusive).

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APPENDIX D: H.O.T. STATS WORKSHEET 3

THE SIGN TEST FOR PROPORTIONS WITH REPEAT MEASURES

I. **DATA.** The practitioner changes a dairy's ration and wonders how production changed. Since milk production is affected by days in milk, an index based on an entire lactation would remove the confounding in milk production from the pre-ration change measurement to the post-ration change measurement because of time. Therefore Mature Equivalent Milk Production (MEMP) was chosen. The number of animals whose measure went up and the number that went down is counted. In this example, suppose after changing the ration the practitioner gets these results for a 67-cow string: increased MEMP = 41, decreased MEMP = 26.

II. **TEST STATISTIC.** The calculation is the absolute value (i.e., ignore final negatives) of the following:
(Total − [2 × lesser of the two] − 1)/(Total$^{0.5}$)
where taking a number to the 0.5 power equals taking its square root.

III. **Z SCORES.** This fits a Z-test distribution, so the appropriate values are (from any statistics text, or see Chapter Appendix A)

80%: 1.28 **90%:** 1.64 **95%:** 1.96

IV. **DO THE MATH.** Plug in the numbers to the test statistic equation and compare to the published "Z" scores:

$$(67 - [2 \times 26] - 1)/(67^{0.5}) = (67 - 52 - 1)/8.19 = 1.71$$

V. **DECISION CRITERIA.** The *decision rule* is similar to before: Since the test value is between the "Z" scores for 90% and 95% confidence, the results show between 90% and 95% confidence that more cows increased MEMP than decreased MEMP after the ration change.

Caveats

To work well, at least 25 pairs of measures (i.e., 25 animals, evaluated twice) are needed. The observations also must be taken at random.

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APPENDIX E: SPREADSHEET STATS WORKSHEET 1

STUDENT'S t-TEST FOR THE DIFFERENCE BETWEEN TWO MEANS

I. DATA. A practitioner is looking at heifer weights, both pregnant and open, to see if a difference exists between the two groups. The values are entered into a commercial spreadsheet to get the following counts, mean weights, and standard deviations:

	Open	Pregnant
Count	15	22
Mean weight	667	676
SD weight	18	22

	Body Weight			Body Weight			Body Weight			Body Weight	
	Open	Pregnant		Open	Pregnant		Open	Pregnant		Open	Pregnant
1.	661	659	7.	691	713	13.	655	690	19.	–	665
2.	650	669	8.	652	678	14.	663	698	20.	–	687
3.	651	709	9.	670	658	15.	701	679	21.	–	679
4.	672	655	10.	690	688	16.	–	700	22.	–	669
5.	671	701	11.	631	669	17.	–	630			
6.	662	640	12.	680	645	18.	–	688			

II. THE STUDENT'S t-TEST (using Quattro Pro 8, Windows)

A. The test is run through a set of menu choices:
Tools / Numeric tools ⇒ / Analysis

B. This starts an automated analysis process. Choose, in order:
1. t-Test <*Next* ⇒>
2. Enter cell range for the 15 nonpregnant animals into *Variable 1 Input*
3. Enter cell range for the 22 pregnant animals into *Variable 2 Input*
4. Select a blank cell with at least 13 blank rows under it for the *Output Cells*, then hit <*Next* ⇒>
5. Click on the button for *Two Sample with Equal Variances*, then hit <*Finish*>. (Don't worry about selecting <*Alpha*> *or* <*Difference*> values.)

C. Starting in the *Output Cells* from step 4, the following is displayed:

t-Test: Two Sample Assuming Equal Variance

	Variable 1	Variable 2
Mean	667	676
Variance	340	498
Observations	15	22
Pooled variance	435	
Hypothesized mean difference	0	
df	35	
t	−1.3	
P (T <= t) one-tail	0.10	
t Critical one-tail	1.69	
P (T <= t) two-tail	0.20	
t Critical two-tail	2.03	

III. DECISION RULE. The *decision rule* is executed by examining the value for the line "P(T <= t) two-tail," which in this case is 0.20. This is the P value suggesting that there is a 20% chance that the difference seen is simply due to random events, and that the true difference could be zero. In other words, the practitioner can be 80% confident that the difference observed is not due to random events. This is just what was found when the Z-test confidence interval for the difference between two means was run in H.O.T. Stats Worksheet 1.

Caveats

This test assumes samples are independently drawn from two normally distributed groups. It cannot, therefore, operate on before and after or paired selection samples.

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APPENDIX F: SPREADSHEET STATS WORKSHEET 2

CHI-SQUARE TEST FOR CONTINGENCY TABLES

I. **DATA.** A practitioner doing fertility work on a dairy has the impression that fresh heifers do not "clean up" as well as fresh cows. The following 2 × 2 table shows the results of the examination:

	Clean	Metritis	Total
Heifers	15	12	27
Cows	42	16	58
Total	57	28	85

II. **THE CHI-SQUARE TEST—GENERAL** (using Microsoft Excel 97, Windows)

A. The first step is to create the table of expected values, following the same process described in H.O.T. Stats Worksheet 2. To reiterate, the analyst calculates the cell sizes, assuming there is no effect of the row factors (i.e., the cells in each column assume the same proportion as the overall proportion for that factor). In this case, it is the following:

Proportion heifers overall = 27/85 = 0.32
Proportion cows overall = 58/85 = 0.68

B. Multiply the above proportions by the sum of "clean" and "metritis" cases to develop the proportion of heifers and cows in each class:

	Clean	Metritis	Total
Heifers	57 × 0.32 = 18.1	28 × 0.32 = 8.9	27.0
Cows	57 × 0.68 = 38.9	28 × 0.68 = 19.1	58.0
	57.0	28.0	85.0

C. A reasonable way the spreadsheet might look, following these two steps, would be as follows:

	A	B	C	D	E	F
1	***DATA***		**CLEAN**	**METRITIS**		
2		**Heifers**	15	12	27	32%
3		**Cows**	42	16	58	68%
4			57	28	85	
5			67%	33%		
6						
7	***EXPECTEDS***		**CLEAN**	**METRITIS**		
8		**Heifers**	18.1	8.9	27.0	
9		**Cows**	38.9	19.1	58.0	
10			57.0	28.0	85.0	

Microsoft® Excel 97, Microsoft Corporation. 1997.

D. Statistical "=" functions can be used here instead of invoking a set of menu commands as in Spreadsheet Stats Worksheet 1. These are functions that perform certain procedures, saving the analyst from doing it all. The functions to be used are as follows:

=CHIINV Computes the inverse of the cumulative one-tailed chi-square distribution and develops the critical value for a test involving a chi-square variable.

Syntax = =CHIINV (Prob, Deg_of_Freedom), where Probability = Cumulative probability value (must be between 0 and 1), and Deg_of_Freedom = Integer number of degrees of freedom (must be ≥1). Calculated as (no. of rows – 1) × (no. of columns – 1)

=CHITEST Computes the probability that the actual and expected frequencies are similar by chance. =CHITEST returns the probability for a chi-square test distribution with (r – 1) × (c –1) degrees of freedom, where r = number of rows and c = number of columns. Actual and Expected must have the same number of values and must contain multiple rows or columns of data.

Syntax = =CHITEST (Actual, Expected), where Actual = Cells containing actual values and Expected = Cells containing expected values.

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These two "=" functions are included in this spreadsheet as shown below:

	A	B	C	D	E	F	G	H	I	J	K
1	***DATA***		**CLEAN**	**METRITIS**							
2		**Heifers**	15	12	27	32%					
3		**Cows**	42	16	58	68%					
4			57	28	85						
5			67%	33%				***CHI STATISTIC*** [a]		2.37	
6								***P-VALUE (2-TAIL)*** [b]		0.12	
7	***EXPECTEDS***		**CLEAN**	**METRITIS**							
8		**Heifers**	18.1	8.9	27.0			a = CHIINV (J6,1)			
9		**Cows**	38.9	19.1	58.0			b = CHITEST (C2:D3,C8:D9)			
10			57.0	28.0	85.0						

Microsoft® Excel 97, Microsoft Corporation, 1997.

III. DECISION RULE: The *decision rule* is executed by examining the value for the cell identified as *P*-value (Cell J6 in the table just shown), which in this case is 0.12. This suggests there is a 12% chance the difference seen is simply due to random events and that the true difference could be zero. In other words, the practitioner can be nearly 88% confident that the difference observed in the metritis rates between heifers and cows is not due to random events. The chi-square test run in H.O.T. Stats Worksheet 2 claimed an 80% to 90% confidence that a significant association was present.

Caveats

As long as no cell has a value less than 5, and as long as the groups are independent and mutually exclusive, the chi-square for contingency tables is a robust and easy method of determining statistical significance in data sets. In other words, this cannot be used for "before-after" comparisons on the same animals (not independent) or in situations in which the classification is not clear (not mutually exclusive).

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APPENDIX G: SPREADSHEET STATS WORKSHEET 3

PAIRED t-TEST FOR THE DIFFERENCE BETWEEN TWO MEANS

I. **DATA.** A practitioner changes a dairy's ration and wonders how production changed. Since milk production is affected by days in milk, an index based on an entire lactation would remove the confounding, therefore the mature equivalent milk production (MEMP) is chosen.

In this example, suppose after changing the ration the practitioner gets these results for a 67-cow string: increased MEMP = 41; decreased MEMP = 26. This is shown below along with other descriptive statistics. Also included is the actual data set itself.

	Average	Standard Deviation	Minimum	Maximum	No. Increased	No. Decreased
MEMP before	22,559	1236	19,783	25,789	–	–
MEMP after	22,621	1327	19,782	25,998	41	26

Cow	Before	After	Diff	Cow	Before	After	Diff
1.	22842	22702	−140	35.	21155	21354	199
2.	22719	22521	−198	36.	22427	22135	−292
3.	23700	23854	154	37.	20461	20409	−52
4.	23995	24271	276	38.	22434	22534	100
5.	23432	23583	151	39.	23647	23812	165
6.	24009	24182	173	40.	19783	19782	−1
7.	23922	24073	151	41.	25789	25998	209
8.	23138	23371	233	42.	24097	24319	222
9.	22839	22590	−249	43.	23147	23247	100
10.	21803	21758	−45	44.	23758	23917	159
11.	22241	22480	239	45.	21922	21816	−106
12.	23352	23154	−198	46.	22977	23328	351
13.	22807	23046	239	47.	22666	22601	−65
14.	23223	22887	−336	48.	23514	23799	285
15.	22247	22140	−107	49.	20154	20344	190
16.	24057	24360	303	50.	22824	22654	−169
17.	23263	22940	−323	51.	20896	20787	−109
18.	22738	22840	102	52.	21578	21447	−131
19.	22445	22626	181	53.	21199	21001	−198
20.	25178	25450	272	54.	20649	20759	110
21.	21979	22278	299	55.	22360	22098	−262
22.	24179	24419	240	56.	20690	20569	−121
23.	21969	22207	238	57.	23911	23976	65
24.	21970	22084	114	58.	21267	21103	−164
25.	23391	23498	107	59.	22263	22629	366
26.	21800	21898	98	60.	21657	21922	265
27.	20192	19917	−275	61.	24642	24280	−362
28.	22365	22276	−89	62.	21481	21660	179
29.	23295	23411	116	63.	21996	22003	7
30.	22670	22874	204	64.	21178	21001	−177
31.	23117	22842	−275	65.	21903	22298	395
32.	22840	22938	98	66.	21922	21989	67
33.	24648	25895	1247	67.	21969	21689	−280
34.	20798	21004	206				

II. **THE STUDENT'S t-TEST** (using Quattro Pro 8, Windows)

A. The test is run through a set of menu choices:
Tools / Numeric tools ⇒ / Analysis

B. This starts an automated analysis process. Choose, in order:
1. t-Test <*Next* ⇒>
2. Enter cell range for the 67 "before" animals into *Variable 1 Input*
3. Enter cell range for the 67 "after" animals into *Variable 2 Input*
4. Select a blank cell with at least 13 blank rows under it for the *Output Cells*, then hit <*Next* ⇒>
5. Click on the button for *Paired Two Sample for Means*, then hit <*Finish*>. (Don't worry about selecting <*Alpha*> or <*Difference*> values.)

C. Starting in the cell selected for the *Output Cells* from step 4, the following is displayed:

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t-Test: Paired Two Sample for Means

		Variable 1	Variable 2
Mean		22,559	22,621
Variance		1,551,915	1,787,997
Observations		67	67
Pearson correlation		0.98	
Pooled variance		1,668,956	
Hypothesized mean difference		0.00	
	df	66	
	t	−2.02	
P (T <= t) one-tail		0.02	
T Critical one-tail		1.67	
P (T <= t) two-tail		0.05	
t Critical two-tail		2.00	

III. **DECISION RULE.** The *decision rule* is executed by examining the value for the line "*P*(T<=t) two-tail," which in this case is 0.05. This is the *P* value suggesting that there is a 5% chance that the difference seen is simply due to random events, and that the true difference could be zero. In other words, the practitioner can be 95% confident that the difference observed is not due to random events. The sign test run earlier claimed a 90% to 95% confidence that more cows went up in MEMP than down. Given how different the data going into the analyses were, this is plenty close for decision making.

Caveats

This test assumes samples are from two normally distributed groups.

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APPENDIX H: SPREADSHEET STATS WORKSHEET 4

SIMPLE LINEAR REGRESSION OF TWO VARIABLES

I. **DATA.** A practitioner suspects that a recent long-term drop in a grass-fed dairy client's milk production, as measured by the herd's changes in rolling herd average (RHA) milk production, could be due to a concomitant increase in somatic cell count (SCC). The practitioner wants to determine, in regression vernacular, whether SCC (the independent variable) plays a major role in describing the variability in rolling herd average (the dependent variable, or outcome). The herd's Dairy Herd Improvement Association (DHIA) records are reexamined, and the last 24 months' data on RHA and SCC are extracted, as shown below. (Note: To run the test, the data should be in single columns for SCC and RHA; they are split here to save space.)

DHIA test date	Estimated avg SCC score	KG rolling herd milk	DHIA test date	Estimated avg SCC score	KG rolling herd milk
Feb-00	3.4	6256	Feb-01	3.8	6141
Mar-00	3.4	6253	Mar-01	3.6	6030
Apr-00	3.5	6156	Apr-01	3.8	6038
May-00	3.7	6161	May-01	3.9	6016
Jun-00	3.6	6148	Jun-01	4.2	5896
Jul-00	3.5	6129	Jul-01	3.8	5900
Aug-00	3.6	6208	Aug-01	4.1	5904
Sep-00	3.4	6191	Sep-01	3.7	6079
Oct-00	3.7	6205	Oct-01	4.0	6011
Nov-00	3.6	6118	Nov-01	3.8	5983
Dec-00	3.7	6196	Dec-01	4.0	5892
Jan-01	3.5	6192	Jan-02	3.9	5867

II. **LINEAR REGRESSION.** (using Quattro Pro 8, Windows)

A. The test is run through a set of menu choices:
Tools / Numeric tools ⇒ /Regression

B. This starts an automated analysis process. Choose, in order:
1. Enter cell range for the 24 SCC observations into *Independent*
2. Enter cell range for the 24 RHA recordings into *Dependent*
3. Select a cell at the top left corner of a blank range of at least 9 rows and 5 columns, for *Output*
4. Click on the button for *Y Intercept/Compute*
5. Click the <OK> button to run the test.

C. Starting in the cell selected for *Output Cells* from step 3, the following is displayed (the "Notes" section is my inclusion and not part of the output):

Regression output		Notes
Constant	7804.87	Theoretical RHA at 0 SCC score
Std Err of Y Est	71.55	Error in estimate
R Squared	0.68	Proportion of variation in RHA explained by SCC
No. of Observations	24	Number of months evaluated
Degrees of Freedom	22	df = n − 2; used in statistical significance tests
X Coefficient(s)	-463.53	RHA change per 1 unit increase in SCC
Std Err of Coef.	67.21	Error in estimate

D. The equation for the regression is built according to the following format (variables underlined are from the above regression output table):

"Y" = Constant + X Coefficient × "X" (R^2 = R Squared)

For the RHA by SCC example, this would be as follows:

RHA = 7804.87 + -463.53 × SCC (R^2 = 0.68)

This can be interpreted as meaning that, with a theoretical RHA production at zero SCC (it does not matter than an SCC of zero is physiologically impossible; this is mathematics and the math can find numerous uses for impossible events!) of approximately 7805 kg, for every unit increase in SCC (i.e., if hard average SCC score moves from a 3.4 to a 4.4), the RHA is expected to change by approximately –464 kg (i.e., to drop 464 kg). This relationship explained approximately two thirds of RHA's variability over the 2-year period observed (R^2 = 0.68 ~ 2/3); something else is needed to explain any more of the variability (perhaps season or demographic changes?).

III. **STATISTICAL ANALYSIS OF THE REGRESSION.** The two main components of a linear regression evaluation for statistical significance is whether (a) the slope of the line created by the regression is different form zero (Hamburg, 1983), and (b) the constant (also known as the y-intercept) is zero (Kilpatrick, 1987). If the regression's slope (e.g., the x-coefficient) is statistically indistinguishable from zero, then the independent variable is not of value in predicting the dependent variable. If the constant equals zero, then the regression must be forced through zero. In this example it makes no sense for the constant to be zero, but the test is run here just for the sake of completeness.

For both tests, if the sample size is less than 30 observations, a t-test distribution for reference should be used. If the sample size is 30 or greater, a Z-test distribution for reference should be used. The test statistic is calculated the same either way. Since the number of observations in this example is 24, the t-test is used.

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A. Test for slope equals zero = x-coefficient / standard error of coefficient
= −463.53/67.21
= −6.90

Using the @TDIST function (Quattro Pro's function to find the probability associated with a t-statistic [syntax = @TDIST (X, Degrees_of_Freedom,2)], or by looking up the t-statistic for 22 degrees of freedom in a statistics book (the negative sign should be ignored if this is done), the test t-value is found to have a related probability of approximately 0.000001. This suggests there is less than a 1 in one million likelihood this correlation is due to chance. Of course, with only 24 observations it is not rational to claim resolution to within seven decimal places—but by any measure this passes the common limits of statistical significance.

In some textbooks (Hamburg, 1983; Snedecor and Cochran, 1989) the authors speak of a test of R2 as the way to determine if the correlation is statistically significant. It is more complicated, requires values not printed out in standard spreadsheet regressions, and gives the same result as noted previously.

B. Test for constant equals zero = constant / (standard error of coefficient^2 × [sum of x^2])$^{0.5}$

This needs a bit of explaining. The "standard error of coefficient^2" means to square the standard error of coefficient. The "sum of x^{2n} means to square each of the x-values and then add them up. Luckily, the spreadsheet has an "@" function that does the job: @SUMSQ (column of numbers holding the x-values)

The last step, taking it to the "0.5" power, is the same as taking the square root of everything. So here is the test for constant equals zero in spreadsheet terms:

= 7804.87/(67.21^2 × SUMSQ *[SCC Scores]*)$^{0.5}$
= 7804.87/(4517 × 333)$^{0.5}$
= 7804.87/1226
= 6.37

Using the @TDIST function (Quattro Pro's function to find the probability associated with a t-statistic [syntax = @TDIST(X, Degrees_of_Freedom,2)]), or by looking up the t-statistic for 22 degrees of freedom in a statistics book (any negative sign should be ignored if this is done), the Test t-value is found to have a related probability of approximately 0.000002. This suggests there is less than a two in one million likelihood this correlation is due to chance. The previous argument, that it is not logical to claim that degree of resolution with only 24 observations, holds. At any rate, this is a significant finding.

Caveats

Linear regression techniques assume, by definition, that two variables are related in a linear fashion. Many associations with which practitioners deal are not linear; therefore they are missed in simple regressions. They also assume that the variation in the dependent variable is the same across the observed values of the independent variable. Again, this is not always the case in biology; often variablility in performance is greater at the extremes than at the middle of a range of normal values. A big assumption of linear regression is that the values of "Y" are independent of each other. If clinic costs are being examined, and costs are low one month, they may be low the next month. The costs, then, are not independent of each other. If clinic costs are regressed over time, however, the regression assumes they are independent of each other. Finally, in regression analysis, the outcome or dependent variable is assumed to carry all the measurement error; the independent variable is assumed to be known exactly. In other words, using the previous example, it is assumed we know SCC exactly (doubtful) so that all the system variation is ascribed to RHA.

Rarely are linear regression's assumptions met in the real world. However, the technique is called, in statistical jargon, "robust." This means that the technique can take fairly major violations of the assumptions and still yield useful data. However, the analyst always should think about these assumptions before embarking on an analysis. The references at the end of Chapter 2 list numerous sources for more in-depth regression analysis, and the "Beyond Spreadsheets: Stand-Alone Statistics Packages" section demonstrates a few of these.

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CHAPTER 3

Record Systems and Herd Monitoring in Production-Oriented Health Management Programs in Food-Producing Animals

JEFFERY K. RENEAU and MARK L. KINSEL

The management information system (MIS), which includes production, health, and financial records, is the foundation of all food animal production–oriented health management programs. These herd records must be of high quality and used skillfully to ensure productive and profitable food animal businesses.

Current management inefficiencies are considered in the same light as clinical or subclinical disease, since they all result in suboptimal performance (Blood et al, 1978; Rollin, 1983; Stein, 1986a,b,c; Lessard et al, 1988; Ruegg, 1996). Identifying the cause(s) of suboptimal performance is often difficult, requiring systematic study of herd records and the application of epidemiological techniques.

Veterinary herd health programs in the past have been focused narrowly and integrated poorly into the farm's total management scheme (Wise, 1988). According to a national survey of producers by the American Veterinary Medical Association, veterinarians are still perceived somewhat narrowly as sources of technical services and information only regarding reproductive management and control of clinical disease. However, beef, dairy, sheep, and swine producers report a high degree of satisfaction with their veterinarian. Veterinarians are highly regarded for their teaching ability and the quality of their advice (Gehrke, 1994; Brown and Silverman, 1999). Large herd owners in particular are looking for a more integrated production-oriented approach (Goodger et al, 1982; Goodger and Kushman, 1983; Fetrow et al, 1987; Fetrow et al, 1988a,b; Guterbock, 1994). It has been suggested that a lack of integrated whole farm "systems thinking" has hampered the success of previous veterinary administered herd health programs (Goodger et al, 1996).

Systems thinking is a discipline for seeing wholes. Today, systems' thinking is needed more than ever because we are becoming overwhelmed by complexity. Perhaps for the first time in history, humankind has the capacity to create more information than anyone can absorb, to foster greater interdependency than anyone can imagine, and accelerate change far faster than anyone's ability to keep pace. Certainly the scale of complexity is without precedent. (Senge, 1990)

Cooperation among the entire farm management team is crucial. The size and technical complexity of livestock operations today make it impossible for any single individual to "know it all." However, each advisor or farm staff member, in spite of his or her area of expertise, must have sufficient knowledge of the entire production system to understand how his contribution fits as an integrated part of the whole. The MIS ties the production system together. It provides a common ground and objectively communicates the successes and failures of the production system. It provides a format fostering productive discussion and timely development of action plans. A systems orientation keeps input from becoming a fragmented insertion of the latest fads and gimmicks. A systems approach among sincere participants enhances cooperation, reminding everyone that the whole is truly greater than the sum of the parts (Nelson, 1999).

Epidemiology is the "core" of preventive veterinary medicine (Schwabe et al, 1977; Schwabe, 1982). It is also the central problem solving discipline in a livestock system. Epidemiological principles, classically applied to the understanding of disease processes, are equally effective in understanding suboptimal productivity. Training in epidemiology is critical for successful implementation of a production-oriented health management program; it is what makes the veterinarian's input unique among all other consultants visiting the farm. Veterinary training in the practical application of epidemiology needs to be emphasized more. This training places the veterinarian in the ideal position to provide guidance in helping the livestock producer successfully integrate all of the disciplines of the production system.

Cognizant that herd health management services offer the greatest long-term potential for revenue growth (Wise, 1987), veterinary professionals have worked to remedy the perception of being too narrow in their perspective. Veterinary colleges have changed curriculum to increase food-animal student exposure to epidemiology, computer literacy and record analysis, herd management, housing, and environment. Veterinary professional organizations, such as the American Association of Bovine Practitioners, American Association of Swine Practitioners, and American Veterinary Medical Association (AVMA), have sponsored countless continuing education workshops and seminars in a concerted effort to build and expand food-animal veterinary expertise. Food-animal practitioners and students who have taken advantage of these opportunities are ready to tackle the challenges of a production-oriented health management practice.

To the new eager veterinary graduate or the experienced practitioner who is wondering how to escape the jaws of traditional food-animal veterinary practice, the authors offer for reflection the following anecdote. *The new infantryman asked his commanding officer: "Sir, where is my foxhole?" To which the officer's reply was quick: "You are standing on it; just dig the dirt out."* The objectives of this chapter are the following:

- To provide a background and greater understanding of the basic principles involved in livestock record use
- To provide guidance in the practical application of herd records for herd monitoring and problem solving

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The chapter is divided into two parts. Part I is a discussion of the basic principles and issues involved in livestock record keeping. Part II is focused on the practical application of livestock records in monitoring and problem solving. Although emphasis is given to dairy record examples, the principles apply in other food-animal species.

Part I: Basic Principles

HERD RECORDS ARE THE KEY

Livestock operations that do not use herd records cannot be taken seriously in today's competitive livestock industry. Conversely, food-animal veterinarians who plan to become involved in production-oriented health management programs must be skilled in herd monitoring and problem solving using the herd records.

Computerized Herd Records Are Preferable

Although manual herd records still may be adequate for small livestock operations, they are not practical for larger commercial enterprises today. Computerized herd records (i.e., Dairy Herd Improvement Association [DHIA] or on-farm computer-based records) are preferred. This fact was recognized over 20 years ago. "In our view, it is necessary for such a system to be computer-based in order to avoid overloading both the farmer and the veterinarian with repetitive tasks of data preparation and analysis." (Blood et al, 1978) Certainly this statement is even more legitimate in today's fast moving and competitive livestock businesses. If manual record systems are going to be used, a daybook approach is preferable (Morrow, 1963; Morrow, 1966a,b; Reneau, 1993). Daily barn sheets or individual cow worksheets that are formatted to make for easy data entry and retrieval are superior to a plain spiral notebook or other ad hoc recording systems.

Computerized Herd Records Improve Herd Management Skill

Computerized on-farm record systems offer many advantages, which not only make them very practical but also have been shown to be profitable investments of time and money. The hypothesis offered is that having accurate, up-to-date records will enhance the quality and timeliness of management decisions. A descriptive study of New York dairy farm managers found that those farms that used on-farm computerized management information systems (Jofre-Giraudo et al, 1990) had the following properties:

- Had more timely up to date records
- Had more detailed and accurate records
- Were less reliant on "rules of thumb" or product-biased information, preferring instead herd-specific data to guide their decisions
- Carried out control decisions more frequently
- Spent more time in management activity and more delegating of routine labor activities
- Were more skilled managers

Certainly these are attributes that would enhance the formation of strong production-oriented health management programs.

Computerized Herd Records Are Economically Sound

It has been difficult to determine the economic value of the adoption and use of a computerized herd record system. Recent attempts have been made to quantify the effects attributable to computerized management information systems (Table 3-1). It seems evident that adoption and use of a computerized MIS is not only practical—it is an economically sound herd management strategy and should be encouraged on all commercial livestock farms.

RECORDS TAKE TIME

Maintenance of a herd record system takes time. Obviously the time it takes depends on the keyboard skill of the computer operator and the amount of data being entered. Different software also varies in the amount of data accepted and the ease of the data entry interface. Computer MISs do not save herd managers time; instead they shift time toward strategic management decisions. Computer tasks take time away from the routine labor tasks that had been previously done by the herd manager. Producers often give time constraints as a reason for not keeping good records. However, studies to date indicate that the time allocation needed to

TABLE 3-1

*Improvements in Herd Performance as a Result of Using On-Farm Computerized Record Systems**

Study	Country	No. of Herds	Species	Performance Change
Lazarus et al, 1990	U.S.	196	Dairy	$85 higher income/cow first year of study
Verstegen et al, 1995	Holland	71 over 10 years	Swine	0.56 more piglets/sow/yr and an increased return over investment of 220% to 348%
Lorsing et al, 1996	U.S.	846	Dairy	207 kg/cow higher RHA
Hayes et al, 1998	New Zealand	438	Dairy	1.2 kg/cow/day more milk and improved reproductive performance
Guilhermino et al, 1997	U.K.	450	Dairy	334 kg more milk/cow/yr and 52 kg more/cow/yr
Tomaszewski, 1997	U.S.	66	Dairy	421 kg/cow/yr increased production
Van Asseldonk et al, 1999	Holland	714	Dairy	62 kg/cow/yr and improved calving interval 5 days

*See references for full source information.

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maintain and use computerized record systems is relatively small and that shifting more of the herd manager's time toward being a decision-maker is beneficial to herd performance (Jofre-Giraudo et al, 1990; Lazarus et al, 1990).

It took dairy producers an average of 37 sec/cow/week to record observations in herd diaries that were then transcribed into a bureau service computer (Lissemore et al, 1992a,b). This was considerably more time than the 16 seconds/cow/week reported earlier in a similar study (Menzies et al, 1988). Expressed in terms of time/100 cows/day, the estimated amount of time required to record data onto a data entry worksheet or into a manual record system would range from 4 to 9 min/100 cows/day.

A 3-year study in 13 dairies with on-farm computers reported the average data entry time of 5.4 min/100 cows/day, and that report generation time added another 1.7 min/100 cows/day (Lissemore et al, 1992a,b). Using a value of $10/hr the computer time cost for data entry and report generation was estimated to be $4.40 per cow per year. A study comparing data entry time of four dairy management software programs found a range in data entry time of 2.5 to 6 min/100 cows/day (Gabler, 1998). This time is dependent on the keyboard skill of the operator, the degree of data entry automation, the amount of data, and the data detail each program would accommodate. Based on these studies it is expected that dairy producers with computerized herd records spend a total time (manual recording on work sheets, keyboard data entry, generating reports) of 6 to 12 min/100 cows/day.

The efficiency of data recording is greatly enhanced by the use of handheld data recorders. Handheld data recorders are being used successfully in a few swine and dairy operations, totally eliminating the transcribing of data from hand-written barn worksheets.

RECORD SYSTEMS SUPPORT DECISION MAKING

As shown previously, record-keeping takes time and costs money. The type of information needed should drive the system for recording data and extracting information. *The information derived should be useful—that is, it should be needed to support some decision or course of action. In addition the information should be used to improve the quality of the management decision.* In general, information needed to support decisions in food animal production can be divided into six categories: single animal decisions, group decisions, monitoring, herd investigation, food safety and quality, and research.

Single Animal Decisions

Is this animal ready to breed? Should she be treated or culled? These types of decisions affect only the individual animal, and the information is needed *now.* They generally require fairly detailed, *up-to-date,* individual animal data.

Group Decisions

The information needed for group decisions is typically for "action lists." Typically these are routine daily or weekly management activities. Which cows need to be dried off? What sows are due to farrow? Which animals are expected in estrus? Which animals are due for vaccination? Which cows should be cultured for mastitis? Which ewes had twins last year? These questions require that the whole population be sifted to select only those individuals with some common characteristics. There are many useful record systems that can produce these lists. But as the population of animals in a herd becomes larger, computerized records are essential to make efficient and timely selection of animals for the appropriate action lists.

Monitoring

Monitoring is the routine, systematic collection and evaluation of information from the farm. Monitors should be strategically selected measures of key processes in the production system. The best monitors are those known to have economic as well as biological outcomes. For example, the bulk tank somatic cell count (SCC) is an excellent indicator of milk quality (economic outcome) and subclinical mastitis (biological outcome) and is an indirect indicator of the management of cow sanitation or the adequacy of the milking routine. The body condition score is an excellent measure of herd nutrition.

A task-responsive monitor that is as directly reflective of changes in management protocol is desirable. For example, in a herd in which the age at first calving is too high, age at first breeding (or conception) is a more responsive measure than age at first calving. In this example measuring age at first calving will require several months before the results of the management change is evident. When lagging reproductive performance is caused by poor heat detection, neither calving interval nor days open may be task sensitive enough to stimulate improved performance. Perhaps weekly measurement of "service rate" would be more effective, with the service rate being the proportion of animals eligible for breeding and expected to be in heat that are actually detected in heat and bred.

Some monitors may be used to help maintain compliance with standard operating protocols. For example, display in the sock filter on the milking parlor bulletin board after each milking provides the milkers with a self-evaluation of whether adequate premilking cow prep is being accomplished. Although these may not be data to record in the herd records, it is a good example of a protocol-sensitive monitor. Monitoring disappearance of supplies and comparing actual usage with expected usage based on compliance with standard procedure are ways of using inventory control as a means of monitoring standard operating procedures.

Routine tracking of these herd monitors is intended to identify emerging problems and to follow performance over time. To act appropriately, herd managers and advisors must monitor the farm's status, noting changes or trends that indicate new conditions that need to be addressed. Livestock producers in general recognize the value of monitoring performance. Dairy farmers in Michigan and the Netherlands indicated a desire for more timely and precise monitoring of animal status and cost control (Huirne et al, 1997).

Herd Investigation

On any farm, unusual, unexpected problems can arise. It is in this area that a veterinarian's epidemiological training becomes invaluable. Answering the questions of who, what, where, and when to characterize the problem is a routine part of every diagnostic investigation. Solving these problems almost always requires the use of records. The storage capacity and process speed of today's microcomputer theoretically make possible the storage and retrieval of all information pertinent to a detailed comprehensive herd investigation. Typically livestock producers get stacks of diagnostic information that clutter shelves and desktops. For lack of a constructive thing to do with them, producers often may just let them gather dust. *Any data that have predictive value for the future are worthy of keeping for future diagnostic use.* The real question of what data to collect and store in the MIS depends

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on the following questions: Will the software being used store and retrieve the data in an informative format? Is the herd manager motivated to enter the data? Is it practical to enter and store data that may never be used? Ideally, a record system should allow the users the flexibility to enter the level of detail that they deem useful based on a balance of their attitude toward risk aversion and the economy of spending time entering "just in case" data. For problems that occur frequently, there is no question that all data that relate to the problem should be kept and, if possible, stored in the MIS for quick retrieval and analysis. For example, milk culture data on clinical mastitis should always be kept so that a periodic analysis of what types of mastitis pathogens predominate can be accomplished. This information will be extremely useful in noting shifts in pathology (environmental versus contagious pathogens) and in designing future mastitis control programs.

Food Safety and Quality

Food safety and quality are of great concern to today's consumer. There is an increased worldwide vigilance to prevent tainted and unwholesome food animal products from reaching the marketplace. In the United States, it has been mandated that all meat and dairy product processing plants have hazard analysis critical control point (HACCP) plans in operation. Since the first critical control point in the food chain for livestock products is the farm, it is logical that HACCP-like programs will trickle down to the farm level. There are already recommendations being made for the tracking and documentation of food safety and quality of food animal products from the farm to the market (Griffin et al, 1998). Obviously this means a need for more records. Some producers and veterinarians may see this as an intrusion. However, in reality it offers food-animal veterinary medicine another great opportunity. The 1994 AVMA study on producer attitudes toward food-animal veterinarians indicated that 50% of beef producers, 33% of dairy producers, 39% of swine producers, and 64% of sheep producers did not think the local veterinarian was very important to the milk and meat quality assurance programs (Gehrke, 1995). The 1998 AVMA market study found that these attitudes still persisted, although 65% of food-animal practitioners feel that veterinarians have an important role in food safety (Brown and Silverman, 1999). It seems obvious that producers need veterinary advice on this topic more than ever. The development of sound, effective treatment protocols for clinical disease is another herd health management opportunity (Rapnicki, 1999). Producers need direction in the design of more appropriate diagnostic (Markusfeld, 1990) and treatment protocols as well as encouragement to properly record clinical treatment data, not only for food safety and regulatory purposes but also to facilitate analysis of the cost effectiveness of treatment protocols.

Research

Record systems are needed to conduct research. Research may be conducted within and across herds. Some of the major improvements in animal agriculture have come from the analysis of pooled records from many farms. The remarkable genetic advances in the dairy industry spring directly from the analysis of breeding records available through the DHIA. Epidemiological studies of the patterns and risk factors of disease depend on record analysis. Research is not limited to those in academia. Practitioners need to use records in their own practice to keep track of local conditions, to test the effectiveness of their efforts, and to demonstrate the usefulness of new services.

FUTURE RECORD DEVELOPMENT NEEDS

At present there are no comprehensive herd health management record systems that can optimally support all the farm decision-making needs. It has long been recognized that a need exists for such an integrated system. This will require standardized data definitions as well as standardized production and health and financial information calculations (Priester, 1975; Rowlands, 1983; Bartlett et al, 1986; Dohoo, 1988; Fetrow et al, 1990; Kelton et al, 1998). Integration between health and production records is commonplace today, but more needs to be done to make this process easier so that a greater impact can be realized (Lazarus, 1990). Integration with financial data is rare. It is notable that the swine industry under the direction of the National Pork Producers Council (NPPC) has developed production and financial standards (Marsh, 1999). The goals of the NPPC for this project were the following:

- "To promote uniformity in production and financial standards for the pork industry by presenting methods for financial and production reporting, which are theoretically correct and technically sound"
- "To present standardized definitions and methods for calculating financial and production measures"
- "To develop a national pork database of standardized production and financial information to allow accurate benchmarking"

Another example of futuristic thinking is the work being done by the National Cattlemen's Beef Association. As a part of the Integrated Resource Management program, the Standardized Performance Analysis (SPA) has been developed. SPA is a systematic method of tracking beef-cow-calf performance. It uses a standard set of guidelines for the calculation of production and financial measures (Collett, 1998; Miller et al, 1998; Collett, 1999). A similar effort to standardize disease definitions in dairy cattle has been suggested (Kelton et al, 1998). These efforts are commendable and should be taken seriously. Much more work in these areas is needed to bring to fruition the idea of the early founders of health management record systems (Cannon et al, 1978; Sundgren et al, 1980; Eddy et al, 1981; Willeberg et al, 1984; Bartlett et al, 1986; Dohoo, 1988) of integrating production, health, and financial information.

DESIRABLE FEATURES OF COMPUTERIZED RECORD SYSTEMS

There are many opinions and preferences regarding basic features of a computerized herd health management record system. Considerable time and thought were devoted to this subject beginning in the late 1960s through the early 1980s (Preister et al, 1975; Cannon et al, 1978; Sundgren et al, 1980; Rowlands et al, 1983; Russell et al, 1983; Willeberg et al, 1984; Bartlett et al, 1986; Dohoo, 1988) These workers outlined data collection, storage, and retrieval standards for development of computerized livestock record systems. Since early microcomputers lacked data storage capacity and processing speed, the first programs were written for use on mainframe machines as a bureau service. The classic example of such a bureau system is the DHIA record system. The DHIA has had a major impact on dairy cattle improvement and genetics (Voelker, 1981). In the basic DHIA program the milk production of each cow in an enrolled herd is weighed once a month by an official supervisor at two consecutive milkings. Milk samples are taken for composition analyses of butterfat and protein content. In many herds the sample is also examined for somatic cell count as an indication of subclinical mastitis. In addition, considerable data on individual cow and herd production, such as feeding information, reproductive events, and cows leaving the herd, are col-

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lected. All these data are processed through DHIA centers, and reports are mailed back to the farmer. If requested by the farmer, copies of the reports can also be mailed to the veterinarian. In some dairy records processing centers (DRPCs), immediate processing and access to the farm's data can be performed over the telephone using a microcomputer. Other processing centers mail diskettes with the herd's data. All DRPCs provide electronic transfer of most DHIA data into on-farm herd management software. These programs are available in Canada, the United States, and other countries. They are usually financed by participating dairy farmers and are often subsidized by provincial or state governments.

The advantages and disadvantages of the bureau approach to records have been reviewed (Etherington et al, 1993). Advantages of the bureau service approach are as follows:

- Data entry conventions are consistent across herds; hence there are more uniform data for multiple herd comparisons
- Producers who do not wish to purchase a computer or learn to use one still benefit from the technology
- Reports are consistent and provided at regular intervals
- Comparison among herds within a practice can be accomplished easily
- Reports are generated and evaluated by someone with experience from a number of herds

Disadvantages noted by the bureau approach authors are as follows:

- Less use can be made of the day-to-day herd management aspects of the programs because of time delay between retrieval of data and delivery of reports
- Increased likelihood of errors in transfer of data from farm to bureau, since data entry person is not as familiar with the situation at the individual farm
- Restriction of the ability of dairy personnel to learn about and improve dairy management through hands-on use of software
- User-defined (custom) reporting capabilities may not be used to full advantage
- Reports and analysis reflect the bureau personnel's interests and goals, not necessarily those of the farm

During the 1980s, microcomputers had advanced to the stage at which the on-farm approach to record-keeping was feasible. For the on-farm approach, all data entry is done on the farm and farm personnel are encouraged to record pertinent events observed during their daily working routines. The advantages of on-farm approach are as follows:

- Computer is on-farm so that data are more current and reports are available at any time
- A person familiar with the animals and events happening on the farm performs data entry
- Dairy personnel have the opportunity to increase their knowledge of the software and dairy management
- The farm computer can be used for multiple farm software applications, including accounting systems, sire summary and selection programs, spreadsheets, and nutritional evaluation programs
- Modem communications allow consultants online instruction to the herd manager should problems arise

These are disadvantages of the on-farm approach as follows:

- Lack of uniformity of data entry across herds (can be overcome with prospective standardization of data entry conventions)
- Greater startup costs to the producer
- Excessive cost because of travel time for consultant unless modem access is available
- Lack of peer-to-peer comparisons for benchmarking
- Lack of standardization of reporting methods and data summary

With today's high-performance microcomputers it seems reasonable to expect future herd management software to be based on the farm. However, hybrid systems have been developed enabling on-farm systems to send and receive data to centralized (bureau) systems. DHI-PLUS and PC-Dart are excellent examples of such integrated systems. Another example of this hybrid system is the use of DairyCOMP 305 record keeping on farms in Minnesota coupled with centralized data processing at the Dairy Regional Processing Center in Tulare, California. If data are standardized for the on-farm system, this hybrid approach offers the benefits of both approaches while minimizing the disadvantages of each.

In view of today's high-performance microcomputers it seems reasonable to expect future herd management software to efficiently accomplish all of the six decision-making categories previously listed. Based on a review of the literature, the ideal on-farm microcomputer system would contain the following characteristics.

Data File Structure

There are many technical and philosophical issues regarding data file structure. Most are beyond the scope of this chapter. Hidden in the "bowels" of software, the data file structure is not obvious to the user. However, suffice it to say the choice of the data file structure may be the single most important design issue in developing an MIS. Every spring during the mud season, workers at a New England farm would post a sign at the end of the long driveway that read, "Choose your rut carefully, you'll be in it for the next ½ mile." The choice of data file structure when developing software is analogous to this quaint anecdote. Knowing something about the file structure of a MIS is helpful in anticipating its analytical capability.

Once the data file structure is set, all analysis and report generation will be at its mercy (Dill, 1992). Ideally the data file structure should accommodate complete animal histories of current and removed animals. In addition, the file structure should not restrict the number of events recorded for animals. Incomplete animal histories result in an erroneous and distorted analysis (current and retrospective) that may mislead the problem-solving process.

Unique Animal Identification

Readable, unique animal identification is critical to most livestock record systems, particularly when dealing with breeding females. Electronic ID systems are now becoming practical options, and it is expected that such systems will be in common commercial use in the future. Record systems simply do not work if all ewes are just ewes, if two sows are numbered 326, or if the cows' ear-tags are too faded to see which ones are in estrus. A surprising number of recording schemes fail at this stage. Until corrected, no effort should be made to implement any higher level records. Even in the case of animals destined for slaughter (feeder pigs, feedlot steers, market lambs), individual identification may become necessary. Current interest in tracking animals from farm to market is gaining acceptance. However, in most cases the pen is the unit of interest and records should reflect the pen's performance. Even here, however, some degree of individual identification is needed to identify sick animals for treatment or drug withdrawal.

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Minimum Data Required

Rowlands (1983) succinctly recommended that an animal record contain two parts: biographical data (ID, birth date, sex, breed, dam, sire, place of birth, herd of residence) and a chronological listing of events that occur during its life. For maximal use all events should be recorded in the simple and consistent format linking ID-date-event.

Data Accuracy

Data accuracy is important to the acceptance and utility of any record system. Errors create mistrust in the information. They weaken the resolve of management decisions and cause hesitance in implementation of an action plan. Several sources of potential error exist in farm record data that may result in biased estimates of disease and risk factor status. Errors result from human failings in data entry or from software shortcomings. Therefore knowledge of both the personnel involved in record processing and the software system being used is required to identify these errors. Errors may be grouped into classes including the following:

- Data entry error
- Logical consistency error
- Duplication error
- Misclassification error
- Computational error
- Selection error
- Software restriction error

Data entry error is the simplest type of error. This occurs when data are incorrectly transferred into the computer. This type of error may be in any one of a number of fields ranging from animal identification to event date or event comments. As a result the effects of this type of error are extremely diverse such that their influence on the outcome of epidemiological studies cannot be predicted. One consequence is logical consistency errors.

Logical consistency errors occur when the data entered do not make biological sense, and such errors are most often associated with incorrectly entered event dates. Examples of these types of errors are estrus lengths of less than 18 days or gestation lengths less than normal length without an abortion occurring. Some software have error-checking capabilities that reduce the rate of these errors. As a means of determining the degree of data entry error, routine screening of data for minimum and maximum values of a field is helpful.

Duplication errors arise in two basic forms: duplicate animal identification and duplicate event data. Duplicate animal identification is a common problem and is the more serious of the two basic forms. This error occurs in herds in which identification numbers are reused, either by recycling ear tags from animals that have been removed from the herd or by using the same number series for mature animals and young stock. In situations in which this type of error has occurred, the data may be useless because the computer cannot recognize the difference in the animals and will combine records. In situations in which hard copies of the original data are available, errors of this type can be corrected by modifying identifications so that all animal names are unique. Fortunately, in most software, the potential for duplicate identification is reduced by alerting data-entry personnel that the identification being entered already exists. Duplicate-event data pose less of a problem and occur when a given event is entered more than one time. Many of the newer software have routines that automatically prompt users if they are entering a duplicate event. The effect of this error in epidemiological analyses is to overestimate the incidence of an event, either disease cases or risk factors. This effect will reduce the risk estimate if the event represents a discordant pair (case without a risk factor, control with risk factor) while enhancing the risk estimate if the event represents a concordant pair (case with risk factor, control without risk factor). This error is most commonly a problem in computer analysis involving "counts" of the occurrence of events and can be avoided easily by listing the event date and event names for count data and screening for duplication.

The *misclassification error* is an unavoidable form of farm-record error and one of the most significant sources of concern. Misclassification error can be defined as the incorrect assignment of an animal's status and is most important in relationship to disease events and potential risk factors. It is produced by three related factors:

1. The lack of standardized definitions for disease or exposure status
2. The inaccuracy of diagnostic procedures
3. The reliance on farm personnel or other nonprofessionals to correctly classify events

A special case of misclassification is recording failure. This may happen if the data are lost, if the disease is not detected ("detection failure"), or if there are differences in case definition. Recording failure results in an underestimation of relative risk. This is of some comfort to the researcher, since risk factors with significant association with disease actually would have a stronger association if recording failure did not exist. On the other hand, the effects of recording failure make interpretation of "negative" associations more difficult.

Computational errors most often occur in situations in which records are hand calculated; however, they may occur within the computer software when the equations used for performance parameters are not standardized or are incorrect.

Selection errors are similar in that they occur because of differences in records used to calculate the numerators and denominators of rates. These errors are also due to a lack of standardization of formulas used to calculate performance parameters. A good example of selection error is the calving to conception interval (also known as "average days open"). As many as five different rates may be calculated depending on the criteria used for the denominator of the equation; all animals in the herd, animals assumed to pregnant, animals confirmed to be pregnant, etc. Effects of these errors are most severe when trying to compare rates across herds; however, as long as the methods used are consistent, the influence of these errors will be minimal.

Software restriction error is specific to the software itself. These errors occur because of coding conventions that are built into the software. An example of this is the situation in one computer program in which a late abortion event is coded as a calving, and calving events can be coded only when the cow has been previously dried off. Thus the dilemma arises of which is worse: adding a dry-off event that does not exist or omitting a known abortion event. The effect of this error is either a recording failure or addition of an event that does not exist. The choice of coding depends on which outcome will have the most deleterious effect. In the example, adding a dry-off event may lead to problems in the milk production data (because of logical consistency error checking), since a cow cannot have milk production if she is dry. It is important to be aware of these errors and always to be consistent in the way they are handled.

Eddy (1982) reported 10 years of experience dealing with data errors in the Melbread (bureau service) and Daisy (on-farm) computerized record systems. The error rate averaged 8% per month in the bureau service system compared with 1% per month with the on-farm data entry. In this case, the

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Melbread system did not have an internal error check system and the DAISY program did. Most systems today do have an internal error system, with DHI being the best example of a bureau system that has an extensive error check system. Embedding an error-checking system into the software is the most effective means of ensuring data-entry accuracy because the prompt identification of an error and immediate request for correction at the farm computer keyboard are the best means to ensure that data accuracy is maintained. Eddy found over 200 different data-entry errors. The most common errors encountered were errors of omission, or events not recorded by the herdsman (dry-off dates, cull dates and reasons for culling, calving dates, and insemination dates). The degree to which errors of omission occur should be considered and factored into the data interpretation. The origin of errors in recorded data occurs at the level of the farm and at the computer.

- Farm level
  - -Lack of or poor (unreadable) identification
  - -Incorrect number recorded (e.g., 369 instead of 396)
  - -Transcription of data to the permanent record system from the herdsman's notebook or memory
- At the computer
  - -Data misread by the computer operator, or operator cannot read the writing
  - -Incorrect keys punched

Pick lists help to improve the accuracy of keyboard data entry, thus reducing the problems of typographical errors. Care must be taken in entering remark-based data to be sure that descriptive information is typed exactly the same.

Data Standardization

There is unanimous recognition of the need for common standards for data definition (production, management, disease, and financial) (Dohoo et al, 1984; Willeberg et al, 1984; Bartlett et al, 1986; Dohoo, 1988; Kelton et al, 1998; Marsh, 1999). Priester perhaps said it best in his comments at the 1975 International Symposium for Animal Disease Monitoring in Guelph, Ontario: *"There are computer specialists who will insist that coding is unduly restrictive, and that most information can be put into the system free form. For those who are tempted to accept such advice, be prepared to pay in programming effort and computer time to get that easily entered data back as usable information"* (Priestler, 1975). Standardization of data definition as well as import and export formats will greatly improve the flow and exchange of data at all levels of the livestock industry.

Attempts to compute the economic cost of disease and the cost benefit of control procedures have been studied for years. Although efforts have been made, the lack of an integrated production, health, and accrual-based financial record system has hampered progress in this area. Fruitful study in these areas will require large standardized databases. All veterinarians need to take seriously the recommendations for standardization of disease definitions. Tables 3-2 through 3-4 are examples of suggested disease definitions of the eight economically important diseases in the lactating dairy cow.

Multiple Herd Comparisons

The ability to easily pool farm-level data into larger multiherd data sets is potentially one of the most powerful benefits of standardizing definitions for data as well as for production, health, and financial calculations. The genetic progress made by studying national DHI databases is strong evidence of this. Identification of genetic markers for study of disease resistance would be greatly enhanced by availability of such a database. Pooling farm data within a practice for herd performance comparison is a powerful benchmarking tool to help identify management weaknesses and motivate clients into taking action (Bartlett et al, 1986; Smith, 1996). Combining herd level data at the veterinary practice, regional, state, or national level increases the scope and accuracy of epidemiological study (Dohoo et al, 1983; Morris, 1983a,b; Bartlett et al, 1986). Veterinarians becoming involved with field research would find such a tool invaluable. The capacity for multiple herd analysis should be encouraged as a standard feature of future livestock MIS.

Many current record systems have already begun to use data dictionaries and pick lists for consistent coding within their database. However, remark-based record systems (systems that provide fields with no restriction on what is entered) that focus on flexibility over consistency provide a significant challenge when conducting retrospective analyses and when pooling data from several herds. This problem can be avoided by those using such systems if they are careful to set up standardized terminology and coding systems for all personnel involved in data entry.

TABLE 3-2

Lactational Incidence Risk (LIR) and Estimated Loss per Case for Eight Common Dairy Cattle Diseases

Disease	Median LIR (%)	Range LIR (%)	No. of References	U.S. Loss/Case ($)
Hypocalcemia	6.5	3-22	33	335
Retained fetal membranes	8.6	1.3-39.2	50	285
Metritis	10.1	2-37	43	
Ketosis	4.8	1.3-18.3	36	145
Left displaced abomasum	1.7	0.3-6.3	22	340
Cystic ovarian disease	8.0	1-16	44	39
Lameness	7.0	1.9-30	39	302
Clinical mastitis	14.2	1.7-54.6	62	

From Kelton DF, Lissemore KD, Martin RE: *J Dairy Sci* 81:2502-2509, 1998.

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TABLE 3-3

Recommended Case Definitions for Eight Common Dairy Cattle Diseases

Hypocalcemia	Clinical signs consistent with stages 1, 2, and 3 of the disease within 72 hours after calving
Retained fetal membranes	Fetal membranes visible at the vulva or were identified in the uterus or vagina by vaginal examination more than 24 hours after calving
Metritis	Abnormal cervical and/or vaginal discharge or uterine contents (not including lochia or clear estral mucus)
Ketosis	Decreased appetite and if there was evidence of elevated urine, milk, or breath ketone levels in the absence of another concurrent disease
Left displaced abomasum	Decreased appetite accompanied by high-pitched tympanic ping in the left abdominal wall between the ninth and twelfth rib
Cystic ovarian disease	A smooth rounded structure greater than 25 mm on one or both ovaries
Lameness	An episode of abnormal gait attributed to either foot or leg regardless of etiology or duration
Clinical mastitis	Visibly abnormal milk (clots, flakes, or watery) in one or more quarters

From Kelton DF, Lissemore KD, Martin RE: *J Dairy Sci* 81:2502-2509, 1998.

TABLE 3-4

Recommended Definition of a New Case for Eight Common Dairy Cattle Diseases

Term	Definition
Hypocalcemia	Only one case per lactation
Retained fetal membranes	Only one case per lactation
Metritis	New case if no observed clinical signs occurred within the last 30 days
Ketosis	New case if no observed clinical signs occurred within the last 30 days
Left displaced abomasum	Rarely more than one case per lactation
Cystic ovarian disease	New case cow had been noncystic for the past 30 days or cyst is present on the other ovary
Lameness	New case if not clinically lame in previous 30 days
Clinical mastitis	New case if there is no abnormal milk from a previously infected quarter for the previous 8 days or there was no abnormal milk in "new" quarter

From Kelton DF, Lissemore KD, Martin RE: *J Dairy Sci* 81:2502-2509, 1998.

Part II. Practical Application

GETTING STARTED

"Great ideas need landing gear as well as wings"

C.D. Jackson, publisher

Yes, even airplanes need wheels. Lofty ideas are no different. Unless they can be brought down to earth and transformed into practical application, they are of little value to anyone. This leads to the following question: what are the requirements of getting a production-oriented health and management program started?

Early proponents listed the following basic farm requirements (Blood et al, 1978):

- Skilled herd manager motivated to improve animal health and productivity
- Skilled veterinarian or advisor who will take interest in the producer's goals and objectives and is willing to apply his or her expertise toward meeting the objectives of the farm
- Animal handling facilities
- All animals uniquely identified
- Herd records and monitoring system

Implicit in these recommendations is that the farm will have a sense of mission and clearly defined goals. Experience has shown that this has been a mistaken assumption and, as a result, many well-intended programs have dwindled by failing to produce anticipated results. In the absence of clear expectations, farm evaluation can even become an adversarial process, whereas mutually agreed-on goals release power and mobilize resources, thus bringing about a more proactive working relationship that tends to shift the focus from "who is to blame" to "what is the best plan for the future based on what we see now." When there is a shared vision of what needs to be done along with clearly understood responsibilities, herd evaluation and monitoring become a tool rather than a threat.

The herd owner's or manager's responsibilities (Drucker, 1974) are as follows:

- Set farm goals and objectives
- Organize assets to accomplish goals and objectives
- Train, communicate, and motivate
- Maintain records and monitor performance

The herd advisor's or veterinarian's responsibilities are to support the herd owner or manager with the following:

- Assisting in herd monitoring
- Providing up-to-date information
- Providing technical and biological expertise
- Providing unbiased professional perspective
- Participating in training or motivating employees

Both the herd manager and the veterinarian must be committed to the philosophy of continuous improvement. Deming has shown that consistent application of this concept results in improvements of both quality and productivity (Wheeler and Chambers, 1992).

Fig. 3-1 is an outline of record use in a production-oriented health management program. The principles of continuous improvement must be the foundation on which

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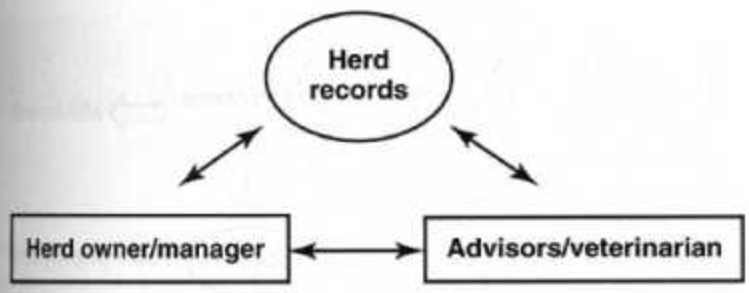

STEP 1: **Farm/animal observations, record evaluation,** and strengths, weaknesses, opportunities, and threats (SWOT) analysis. Select mutually agreed-on goals by using "goal form" or benchmarking tools. } Build knowledge; create a shared vision.

STEP 2: **Select area(s)** (i.e., nutrition) and focus on the process(es).

STEP 3: **Select monitor** and measure actual performance, which in process-control language is called "voice of the process."

STEP 4: **Select target** of performance based on goals, which of process-control language is called "voice of the customer."

STEP 5: **Deming cycle:** Continue follow-up monitoring, evaluating, planning adjustments in protocols, and tasks within the process and supervise implementation of the plan. This is a continuous process to close the gap between the desired target and the actual performance.

FIG. 3-1 Outline for record use in production-oriented health management program.

such a program is designed. A production-oriented health management program is a continual quest for improvement of herd productivity and profitability. Viable programs require maintaining a focus on identifying emerging problems and a commitment to their solution. While monitoring herd performance may be interesting, it is pointless if there is not a continuous commitment to recognizing and solving herd problems.

Step 1: Record Use in Goal Setting

The first step is setting goals. Benchmarking is an excellent tool to use in a goal-setting discussion. Identification of the herd's strengths, weakness, opportunities, and threats (SWOT analysis) is a productive starting point. An example of another effective approach is the "goal form" (Chapter Appendix 1), which Nordlund (1993) developed to identify dairy herd problems and establish production goals. It is very useful as a tool for the initial farm visit and for periodic reevaluation of herd performance as a means of avoiding program stagnation. Wassell and Chamberlain (1994), using a similar approach in the United Kingdom, reported a high level of acceptance by both farmers and veterinarians. Completion of the "goal form" with the dairy manager can increase commitment to solving herd problems and monitoring herd performance.

The "goal form" is designed to:

1. Be *completed in a discussion with a client*
2. Use the *client's records and estimates of costs* whenever possible
3. Provide a *limited economic assessment* of different production problems
4. Provide a format to *mutually agree on production goals* for the herd
5. Set the stage to *develop a plan* to accomplish these goals

TABLE 3-5

Considerations for Appropriate Goal Selection

	Should the plan be implemented?	
Consideration	**No**	**Yes**
Potential return	Low	High
Cost to implement	High	Low
Interval to effect	Years	Weeks
Odds of success	Questionable	Certain
Impact of failure	Bankruptcy	Minimal

From Kelton DF, Lissemore KD, Martin RE: *J Dairy Sci* 81: 2502-2509, 1998.

Completion of the form requires several pieces of information (records): the number of heifers on the farm that have not calved, the girth and height of recently calved heifers, current milk-plant pricing policy, and the on-farm computer or DHI herd summary sheet. In addition, records or estimates of heifer deaths, clinical mastitis case rates, and a variety of prices will be needed. Experience indicates that it takes approximately 2 to 3 hours to complete the form and the resulting discussions.

The form is divided into sections: replacements, culling, udder health, reproduction, genetics, and nutrition. References used as a basis for the calculations suggested are given in the text of the form. A caution should by noted with regard to the genetics section. Predicted transmitting ability (PTA) values should be updated annually. Most DHI processing centers routinely update these values and are willing to share the information.

Step 2: Selection of Goals

The intent and limitations of the "goal form" need to be made clear. The goal form is designed to bring attention to the big opportunities for a dairy and assist in the goal-selection process. The exercise also provides valuable insight into the status of the herd's records. The equations in the form produce gross economic estimates of the losses the dairy incurs annually in failing to meet the specified targets of performance. The costs of achieving the goals are not estimated. Thus the form is simplistic as an analytical tool. However, attempts to estimate net benefit of achieving a goal usually make the process too unwieldy and extensive to accomplish in 2 to 3 hours. The rationale is that a less-than-precise tool that can be completed may be more effective than a precise analysis that is rarely done. The "goal form" was designed to depend on data that were readily available on most dairy farms, and the process had to take less than 3 hours to complete. Some effort has been made to make the process more realistic by avoiding counting the same problem twice.

Goals and plans are usually selected simultaneously. Users of the form tend to rank problems in order of highest dollar amount and create a goal based on the biggest item. This may be correct sometimes, but the area selected for change should be based upon several considerations, which are listed in Table 3-5. Two examples may be useful in demonstrating this idea. There may be indications of large losses in the mastitis section of the goal form for one client.

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After some investigation, the problem appears to be due to environmental organisms and the plan would involve increasing the vacuum level to reduce liner slips and the initiation of a predip program. Should the plan be implemented? The potential return is high, the cost to implement the program is minimal, the interval to effect would be weeks or days, the odds of success are good, and the impact of failure would be that things remain as they are now. All considerations say YES, the program should be implemented.

The mastitis section may indicate the largest dollar losses on a neighboring farm. However, after further investigation, it may be discovered that this second dairy has a high level of *Staphylococcus aureus* infections and an inadequate milking system. Modernization of the milking system will cost $25,000, and perhaps 25% of the herd should be culled. A review of the "considerations" (Table 3-5) shows that the potential return also may be high as in the earlier example. However, the interval to effect may be months and the odds of success uncertain because of inconsistent milking practices, which suggests a "maybe." Notwithstanding, the cost to implement is high, and the added debt might make the farm vulnerable to bankruptcy if they experienced a poor crop year in addition to their current precarious debt situation. These considerations would make this plan less attractive. In this situation the client should be advised to consider the decision further, perhaps to develop partial budgets to study the issue further and to obtain professional financial advice regarding farm debt management. Perhaps the client should find other areas of the goal form that could yield income more quickly and with lower risk to the operation. Regardless of what goals are selected, they should be SMART (specific, measurable, attainable, rewarding, and timed) goals. The selected goals in this case become the "target of performance" or, in the language of process control, "the voice of the customer"(Fig. 3-2). In this case the customer is usually the herd owner or manager; however, it also could be the milk plant or packing house.

Step 3: Selecting the Monitors

The monitor is the measurement of the actual performance of the process, which in the language of the process control is called the "voice of the process" (Fig. 3-2). Since it is impractical to measure everything, it is important to select the most critical measurements, which are the best reflections of the process behavior. Monitors should have a correlation with the goals (e.g., profit). They must be easy to measure precisely and accurately, and they should have as little "lag" or "momentum" as possible. Carefully selected task-sensitive monitors are best. For example, if heifer management were identified as the problem area because the average age at calving was too old, then average age at calving would not be the best monitor to use. This monitor has too much lag. The average age at conception would be more appropriate, since it is a more timely reflection of those tasks within the heifer reproduction process that result in pregnancy.

Step 4: Selecting a "Target"

A target of performance should always be selected based on the mutually agreed upon goals generated from the goal form or benchmarking exercise.

Step 5: Deming Cycle

Follow-up is an essential component of successful programs. The Deming cycle with a focus on continuous improvement represents a subtle but powerful change in management attitude. The "target of performance" is now not just an arbitrary number from a page of published guidelines or benchmarking data; it is an attainable, mutually agreed upon goal tied into a continuous plan of action designed to improve the process(es) involved until the goal is reached. Once the goal is reached and the process is stable, monitoring is continued as a means of verifying that the system remains "in control." In this case "in control" means that the process is stable and predictable. If the herd owner decides further improvement is needed, the "target of performance" is reset, the process is redesigned, and adjustments are made until the new goal is reached and the process is once again stable. This same procedure can be performed for every process within the entire production system. Thus a program organized in this manner is a continual quest for process improvement.

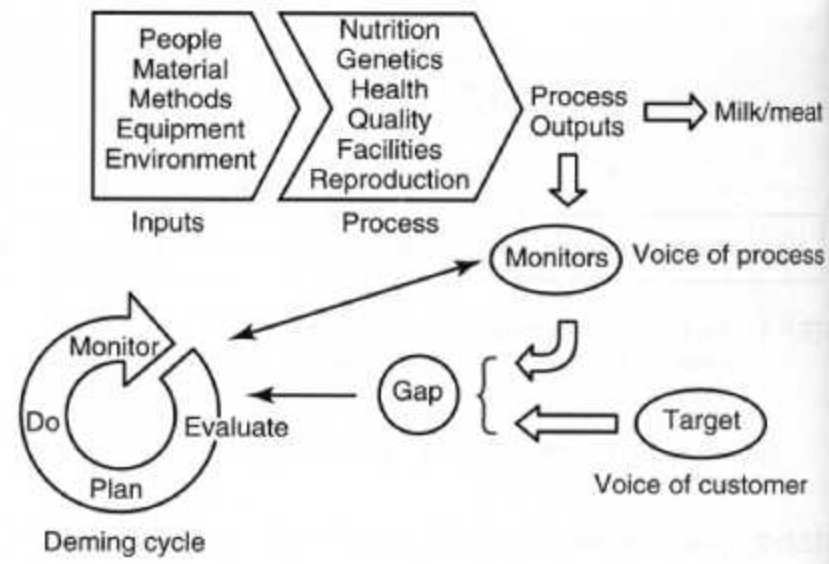

FIG. 3-2 Livestock production system process control diagram.

Deming points out that all processes fall into one of four states (Fig. 3-3):

- Ideal state
  - –The process is in control
  - –The performance target is being met 100%
- Threshold state
  - –The process is in control
  - –The performance target is not met 100% of the time
- Brink of chaos
  - –The process is out of control
  - –The performance target is being met 100%
- State of chaos
  - –The process is out of control
  - –The performance target is not being met

It would be rare and probably impossible to find a livestock operation with all of its processes in the "ideal state." It is obvious from study of herd records that the best farms have proportionately more of the production system processes in the "ideal state" and fewer in the "state of chaos" than poorly managed farms. The objective of a production-oriented health management program is to move each production system process toward the "ideal state."

There is a universal force acting on every process that over time causes deterioration, decay, wear and tear, breakdown, and failure. This is called "entropy." Morris et al (1978a) recognized that the difficulty of maintaining mastitis control measures is almost inevitable. Turnover in employees, taking short cuts on established protocols, wearing out of equipment and facilities, and running out of critical supplies are all examples of process entropy. Without attention all processes eventually migrate to a "state of chaos." The only way to overcome this natural process is to continually repair the effects of process entropy. Routine repair and mainte-

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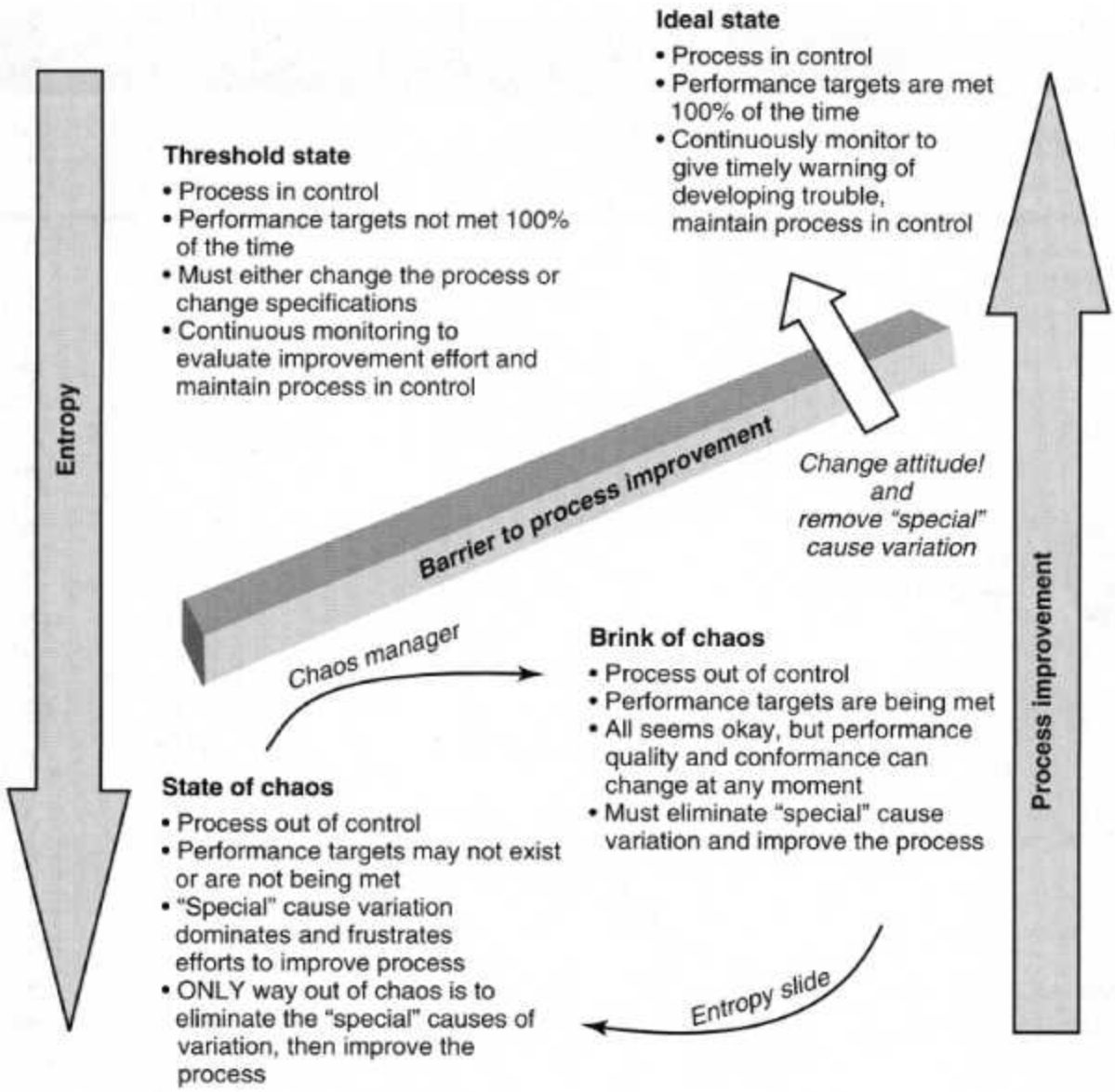

FIG. 3-3 Process status in a livestock production system. (Adapted from Wheeler DJ, Chambers DS: *Understanding statistical process control*, Knoxville, Tenn, 1992, SPC Press.)

nance of equipment and facilities and training of employees are examples of process entropy repair. The more proactive and consistent the farm is in maintaining optimal function of each process, the more likely that they will succeed in reaching and maintaining the "ideal state."

Veterinarians frequently are called to a farm to respond to a process in a "state of chaos." The farm personnel have a situation in which they know they are in trouble. For example, the bulk tank SCC has just exceeded the legal limit, and the farm has been issued an ultimatum to lower the bulk tank SCC or face the consequences of losing their market. The farmer is asking for the veterinarian to be a chaos manager. The farmer's expectation is to get the SCC down to legal limits as soon as possible. Using diagnostic skill the veterinarian identifies the chronically high-SCC cows and may recommend culling some of those cows and the use of a quarter milker on a few other high-SCC quarters. The goal has been achieved. With the veterinarian's assistance, the farm is now able to sell their milk again; the farmer is happy and feels temporarily out of trouble. However, even though the milk now conforms to the legal standards, in reality the processes that govern milk quality have not changed and are still likely "out of control." The veterinarian's intervention as a chaos manager has moved the situation from a "state of chaos" to the "brink of chaos." However, without further intervention to change the processes, this herd is doomed to slip back into a "state of chaos" and the cycle of despair continues.

The greatest barrier to achieving the quality of management depicted by the process in the "ideal state" is attitude. The only way to sufficiently overcome process entropy and reach the more desirable "threshold" and "ideal" states is by commitment to the concept of continuous process improvement and a continuous monitoring system that alerts the herd manager to the effects of process entropy. The causes of abnormal ("special cause") variation must be found and eliminated, and then emphasis must be placed on process improvement. This is why it is critically important that herd manager and the veterinarian have a shared vision of what the goals are and a firm commitment to the long-term process of continuous improvement.

Guidelines and Benchmarking

Guidelines

Table 3-6 is an example of dairy performance guidelines. These values are useful in gauging herd performance and setting goals. However, guidelines must be kept in perspective. They are often a collection of independent values, some of which are based on research and some based on the experience of industry experts. They are usually out of context of any real production system and may be even out of date. Therefore the guidelines may not directly apply to a specific livestock operation. They should be taken as "ballpark" values and not as "gospel."

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TABLE 3-6

Target Guidelines and Intervention Levels for Dairy Farms

	Target	Action	Client
PRODUCTION			
Milk per cow per day (lb)	>75	<70	
Management level milk (MLM) (lb)	>75	<70	
Peak milk (lb)	>95	<90	
Peak first (lb)	>80	<75	
Peak others (lb)	>105	<98	
Peak ratio (first/other)	0.75-0.80	<0.75 or >0.80	
REPRODUCTION			
Average days in milk	160	>180	
Calving to conception (days open)	110	>130	
Pregnancy rate (PR) (%) (HD × CR = PR)	>25	<20	
Heat detection (HD) (%)	70	<50	
Conception rate (CR) (%)	50	<40	
Average days dry	55	<40 or >70	
Pregnant at pregnancy check (%)	80	<75	
Dystocia (%)	7	>10	
CULLING			
Leaving, first lactation (%)	10	>15	
Leaving, others (%)	15	>20	
Total culled (%)	25	>35	
Herd culled for infertility (%)	<5	>10	
MILK QUALITY AND MASTITIS			
Herd average bulk tank SCC/ml	<200,000	>300,000	
New infection (%)	<5	>10	
Herd > 200,000 SCC/ml	<20	>20	
No. clinicals/100 cows/month	<2	>3	
HEALTH (Lactational Incidence Risk)			
Hypocalcemia	<2	>5	
Retained fetal membranes	<10	>15	
Metritis	<10	>15	
Displaced abomasum	<2	>5	
Ketosis	<5	>10	
Cystic ovarian disease	<8	>15	
Lameness	<5	>10	
GENETIC			
Cows from AI sires (%)	100	<80	
YOUNGSTOCK			
Age at first calving (mo)	24	>26	
Average weight at calving (lb)	1200-1300	<1200	
Calves born dead (%)	<8	>12	
Calf death loss (day 1 to weaning) (%)	<3	>5	
Calf death loss (weaning to 1 year) (%)	<2	>3	

SCC, Somatic cell count.

Benchmarking

The 1998 PigCHAMP database (Table 3-7) (PigCHAMP Inc, Apple Valley, Minn.) is a good example of benchmarking data. The only real reason to use benchmarking is to improve on existing performance in an objective way. Benchmarking is a performance measurement tool used in conjunction with improvement initiatives to measure comparative operating performance of similar livestock businesses. Benchmarking is way to discover impending problems and assist in pointing out opportunities for improvement. It fosters the questions of *"Are we doing the right things?"* (effectiveness) and *"Are we doing things right?"* (efficiency) (Smith, 1996). Benchmarking is superior to the use of guidelines since the values are "real" and "in the context" of similar commercial

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TABLE 3-7

PigCHAMP Database (U.S. Summary, 1998)

	No. of farms	Average	Upper 10%	Your farm
BREEDING PERFORMANCE				
Repeat services (%)	612	14.4	6.3	
Multiple matings (%)	612	85.2	99.6	
Entry-to-service interval (days)	501	37.9	14.6	
Sows bred by 7 days (%)	612	83.2	93.7	
Weaning-to-first-service interval (days)	612	8.2	5.7	
Average nonproductive days	501	85.2	53.3	
FARROWING PERFORMANCE				
Average parity of farrowed sows	612	3.5	4.4	
Farrowing interval	612	150	141	
Farrowing rate (%)	612	73.2	85	
Average total pigs/litter	612	11.2	12.0	
Average pigs born alive/litter	612	10.2	10.9	
Average stillborn pigs	612	0.82	0.5	
Average mummies per litter	612	0.18	0.1	
PWM for farrowed and weaned	612	13.1	8.9	
Litters per female per year	612	2.10	2.36	
Litters per mated female per year	612	2.23	2.46	
WEANING PERFORMANCE				
Pigs weaned/litter weaned	612	9.0	9.7	
Average age at weaning	612	18.9	14.5	
Adjusted 21-day litter weight (lb/kg)	529	124	143	
Pigs weaned per sow	612	8.8	9.5	
Pigs weaned/mated female/yr	612	19.7	22.8	
Pigs weaned/female/yr	612	18.6	21.9	
POPULATION				
Average female inventory	612	624	1384	
Average gilt pool inventory	501	41	80	
Replacement rate (%)	612	58.5	36.8	
Culling rate (%)	612	45.5	27.8	
Death rate (%)	612	5.9	2.0	
Average parity of culled sows	612	3.7	5.3	

PigCHAMP GROWTH DATA, 1998 **Weights from 55.0 to 243 lb**	**No. of groups**	**Average**	**Upper 10%**
Average daily gain (lb)	2544	1.61	1.94
Average daily feed intake (lb)	2494	4.98	5.44
Feed efficiency	2494	3.12	2.84
Mortality rate	2544	2.8	0.8

Courtesy of PigCHAMP Inc., Apple Valley, Minn.

production systems. Benchmarking databases are periodically updated and often published by state or region. Therefore they may reflect more accurately performance under current conditions. These values offer a convincing comparison and a powerful means to identify your client herd's strengths and weaknesses. However, benchmarking does have shortcomings. Benchmarking tells where the practitioner is in relation to other similar operations but it does not tell how he or she got there or how to get out of the current mess. Therefore benchmarking is not a stand-alone analytical procedure and must be teamed with other more diagnostic techniques to resolve the cause(s) of suboptimal performance and derive appropriate action plans.

Table 3-8 is another example of a benchmarking database in which the management variables have been arranged in columns based on level of herd productivity. DHIA organizations are excellent sources of benchmarking databases for dairy herds. Table 3-9 is a beef-cow-calf database. The CHAPS software provides, via the Internet, a benchmarking database for cow-calf herds. This particular database represents data from over 200 cow-calf herds and more than 100,000 cows. All are good examples of the application of benchmarking as a performance measurement tool.

Standardization of data definitions and the calculations of performance measures facilitate the pooling of individual herd data into benchmarking databases. It is for this reason alone

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TABLE 3-8

*Minnesota Dairy Herd Improvement "Yardstick" 1999**

	<14,000 14,999	14,000- 15,999	15,000- 16,999	16,000- 17,999	17,000- 18,999	18,000- 19,999	19,000- 20,999	20,000- 21,999	21,000- 22,999	22,000- 23,999	23,000- 24,999	24,000+
YEARLY ROLLING AVERAGE												
No. of herds	169	150	216	322	399	447	424	410	321	237	154	203
Cows per herd	49	54	58	63	63	65	70	76	91	106	98	112
Cows in milk (%)	84	85	85	86	87	87	87	87	87	87	88	88
Avg. days in milk	203	198	192	189	189	186	184	182	184	181	185	185
Milk (lb)	12710	14549	15516	16538	17509	18495	19502	20485	21462	22463	23459	25494
Fat (%)	3.86	3.85	3.84	3.81	3.81	3.78	3.77	3.72	3.73	3.72	3.72	3.68
Protein (%)	3.21	3.23	3.20	3.20	3.20	3.19	3.18	3.18	3.18	3.17	3.18	3.17
SCC-linear score	3.8	3.6	3.4	3.4	3.3	3.2	3.1	3.1	3.0	2.9	2.9	2.9
SCC positive (%)†	45	42	39	38	36	34	33	32	30	29	28	28
Management level milk (lb)	44	50	53	56	59	62	64	67	71	74	77	83
AVERAGE SIRE PTA (ADJUSTED FOR GENETIC TREND)												
Avg PTA$, service sires†	227	229	234	230	237	239	239	239	242	243	250	248
Avg PTA$, first lactation	146	145	149	157	162	164	167	169	171	173	182	180
Avg PTA$, other cows	107	114	117	120	130	129	138	140	140	143	151	149
FIRST LACTATION VERSUS OTHER COWS												
% of herd, first lactation	29	32	33	34	36	36	37	37	37	38	39	38
Avg age at freshening, first lactation	30	29	29	28	28	28	27	27	27	26	26	26
Avg age at freshening, other cows	61	59	59	58	57	57	55	55	54	53	53	53
% Sire ID, first lactation†	50	53	57	63	67	72	76	80	79	82	85	87
% Sire ID, other cows†	51	56	59	65	72	75	78	81	82	83	87	88
Avg peak lb, first lactation†	51	57	59	62	64	66	69	71	74	76	79	83
Avg peak lb, other cows†	65	72	75	78	81	84	88	92	95	98	101	108
Peak ratio, first lactation vs other cows†	0.79	0.80	0.79	0.79	0.79	0.78	0.78	0.78	0.78	0.78	0.78	0.77
% Leaving herd, first lactation†	8	11	10	11	11	11	10	11	11	10	11	10
% Leaving herd, other cows†	33	35	32	33	32	31	33	31	31	30	31	30
DAYS DRY BEFORE CALVING												
Avg days dry	72	68	67	67	65	65	64	65	63	63	62	62
Dry less than 40 days (%)	19	15	13	12	11	9	8	7	6	6	5	7
Dry 40 to 70 days (%)	45	53	56	60	63	65	69	69	73	73	76	76
Dry more than 70 days (%)	35	33	31	29	26	25	24	24	21	21	19	18
REPRODUCTION												
Minimum calving interval (mo)†	17	15.9	15.4	15.2	15.0	14.9	14.6	14.5	14.5	14.4	14.5	14.6
Apparent waiting period	85	84	73	73	68	69	64	62	63	60	60	63
Avg days to first breeding	168	148	132	128	120	116	109	104	104	101	100	103
Avg days open	217	197	182	176	171	166	159	155	155	153	154	157
Conception rate	61	58	55	55	54	52	51	50	49	49	46	46
Heat detection index†	34	38	38	39	41	41	43	44	45	45	46	47

PTA, Predicted transmitting ability; *SCC*, somatic cell count.

*Holstein rolling herd averages, Sept 1998.

†Note: highlighted variables are those most closely related to production level. Individual herds may deviate drastically from averages on any variable indicating management difference.

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TABLE 3-9

CHAPS Cow-Calf 1998 NCBA-IRM-SPA Values for Reproductive and Production Performance Measures

	Mean	SD	Top Third*	Middle Third*	Bottom Third*
REPRODUCTIVE PERFORMANCE MEASURES					
Pregnancy percentage	93.2	4.5	94.4	93.6	91.7
Pregnancy loss percentage	0.7	1.4	0.5	0.7	1.0
Calving percentage	92.6	4.8	93.9	93.0	90.9
Calf death loss	4.3	3.8	2.8	4.0	6.5
Calf crop or weaning percent	89.1	6.3	91.9	89.7	85.2
Female replacement rate percentage	20.8	9.9	19.2	20.9	22.8
Calf death loss, % of calves born	4.6	4.2	3.0	4.3	7.3
Calves born first 21 days (%)	58.3	16.6	59.8	58.5	56.5
Calves born first 42 days (%)	86.2	11.2	87.0	86.1	83.3
Calves born first 63 days (%)	95.5	6.2	96.6	95.3	93.5
Calves born after 63 days (%)	4.5	6.2	3.4	4.7	6.5
PRODUCTION PERFORMANCE MEASURES					
Average age at weaning (days)	200	22.9	194	201	209
Actual weaning weight for steers	566	66.3	593	561	537
Actual weaning weight for heifers	539	57.7	563	537	515
Actual weaning weight for bulls	606	86.8	640	600	561
Average weaning weight	557	60.9	584	556	530
Weight weaned per exposed female	490	72.1	533	493	435
Age-adjusted weight weaned/ exposed female			552	492	417
CULLING % BASED ON TOTAL COWS EXPOSED					
Total percent culled	13.5	8.0	13.1	12.7	14.0
Dead (%)	0.9	1.3	0.6	0.9	1.3
Culled due to age (%)	2.2	3.8	2.3	2.0	1.9
Culled due to defects (%)	1.5	2.5	1.4	1.8	1.2
Culled due to infertility (%)	4.7	3.6	4.1	4.4	5.1
Culled due to inferior calves (%)	1.3	2.5	1.4	0.8	1.5
Culled for replacement stock (%)	1.9	5.1	2.0	1.8	0.9
Culled for unknown reasons (%)	1.1	3.9	1.4	1.0	2.3

CHAPS, Cow herd analysis program; *NCBA-IRM-SBA*, National Cattlemen's Beef Association–Integrated Resource Management–Standardized Performance Analysis.

Adapted from Ringwall KA and Helmuth KJ, 1999. Available at: http://www.ag.ndsu.nodak.edu/dickinso/research/1998/beet98a.htm (accessed September 28, 2000).

*Herd productivity level selected on the basis of age-adjusted weight weaned per exposed female.

that the livestock industry should follow the lead of the NPPC in creating industry-wide standardization of production and financial standards. Likewise, standardization of disease definition (Kelton et al, 1998) would permit similar benchmarking benefits regarding subclinical and clinical disease.

The use of both guidelines and benchmarking is a means by which veterinarians can motivate livestock producers to achieve higher levels of performance by fostering increased expectations that are economically realistic. Benchmarking, in particular, is a tool, that if used wisely can prevent program stagnation by promoting the attitude of continuous improvement.

DATA, INFORMATION, AND KNOWLEDGE

The only reason for record use is simply to *know* what is happening. Knowledge is defined as an understanding and clear perception of reality. Knowledge is power. On the other hand, lack of knowledge leads to powerlessness. It is clear that the foundation on which timely and accurate herd management decisions are made is based on knowledge. Ideally this *knowledge* is gleaned from thoughtful consideration of *information* generated from usefully summarized *data* that have been recorded into a herd *MIS*. The best type of data summary and the usefulness of the information are situation specific; they depend on the question being asked.

As an example, the data in Table 3-10 are from a farm that experienced a dramatic increase in their average SCC in July. This sudden increase in SCC was a result of cows becoming infected with mastitis. The list in Table 3-10 includes only those cows in the herd with high SCCs. Imagine the same list if it included all cows in the herd, both milking and dry (about 200 animals). The expanded list would include much more data but would be cumbersome and, in effect, have less informational value. The question at hand (why did the SCC increase?) is more easily addressed by looking only at the cows with high counts. Table 3-11 includes the same data, but here the cows have been sorted by lactation number and days in milk and new infections are indicated. Cows are presumed newly infected if their SCC was low in

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the previous month (linear score less than 4) and high in the current month (linear score greater than or equal to 4). In Table 3-11 it is even easier to see that most of the new cases of high counts are first-lactation heifers in early lactation. However, the practitioner must be careful not to jump to conclusions too quickly until herd demographics are taken into account fully. If, for example, this was a newly started dairy in which mostly first-calf heifers had been purchased, a conclusion that the problem was new infections in early lactation heifers might be incorrect. In fact it could be that the proportion of second and third lactation cows with new infections in early lactation might be equal to or greater than

TABLE 3-10

*Sample Mastitis Outbreak: Data from Cows and Heifers with High Somatic Cell Counts (SCCs)**

ID	Lactation number	Last month (SCC linear score)	This month (SCC linear score)	Days in milk
2483	6	6	7	382
2713	3	7	9	567
2497	6	6	8	361
2962	1	–	7	44
2223	7	6	7	331
2543	5	5	6	407
2980	1	–	6	39
2958	1	–	8	33
2407	7	5	6	345
2824	2	4	8	509
2944	1	–	7	33
2910	1	4	7	396
2930	1	1	5	236
2949	1	7	7	278
2987	1	3	8	50
2791	3	3	7	253
2426	6	5	8	252
2776	3	–	8	185
2898	2	–	7	63

*Only animals with high SCC this month are shown.

TABLE 3-11

Sample Mastitis Outbreak: Data from Cows and Heifers with High Somatic Cell Counts (SCCs)

ID	Lactation number	Last month (SCC linear score)	This month (SCC linear score)	Days in milk	New Case
2944	1	–	7	33	*
2958	1	–	8	33	*
2980	1	–	6	39	*
2962	1	–	7	44	*
2987	1	–	8	50	*
2930	1	1	5	236	*
2949	1	7	7	278	
2910	1	4	7	396	
2898	2	–	7	63	*
2824	2	4	8	509	
2676	3	5	8	185	
2791	3	3	7	253	*
2713	3	7	9	567	
2543	5	5	6	407	
2426	6	5	8	252	
2497	6	6	8	361	
2483	6	6	7	382	
2223	7	6	7	331	
2407	7	5	6	345	

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that in first lactation heifers. The point is that when considering disease rates within a population, practitioners must consider denominators before drawing accurate conclusions. Once this is done, the summarized data in Tables 3-10 and 3-11 become valuable information. The herd's veterinarian can now investigate why first-calf heifers in early lactation seem to be at unusually high risk of new cases of mastitis.

Converting Data to Information

Information is the result of the conversion of raw numbers (data) into an organized or summarized form. The goal of converting data to information is to present all essential pieces of knowledge from a collection of raw numbers in the simplest way possible. The question is how the best or most information can be gleaned from the production systems. For livestock record systems, information can be divided into three general types of output: lists, numerical reports, and graphical reports. Lists are raw data summarized into columns, numerical reports include counts (tallies) and statistics, whereas graphical reports include scatter-plots, histograms, survival curves, and time series plots. Each type of report has strengths and weaknesses that are important to consider when interpreting results.

Lists are the simplest form of information but are the most difficult to interpret, since they do little to process data into a succinct form. Tables 3-10 and 3-11 are good examples of how strategic sorting enhances the use of tabular data. A *numerical report* is a text-based summary based on mathematical calculations. Numerical methods remove extraneous detail by expressing, in numerical form, specific characteristics of the data (Wheeler and Chambers, 1992). Information may be counts of values meeting a set of criteria (frequency distributions or cross-tabulations) or summary measures such as averages (statistics) (Fig. 3-4). A general disadvantage of numerical reports is that they are nonintuitive. In other words, it is difficult to visualize patterns in data just by looking at "the numbers."

Graphical reports are reports that summarize information into visual patterns. In general graphical reports are much more powerful then numerical reports, since inferences may be "seen" in the image; hence the axiom "A picture is worth a thousand words." However, two general disadvantages exist for using graphical reports:

1. Graphical reports can, at most, represent three dimensions
2. The dangers associated with using different scales for axes

The fact that graphs can represent only three dimensions becomes a problem when analysis of complex systems is conducted. Being able to "see" only part of the relationships may lead to inappropriate conclusions, as the whole may be more than the sum of the parts. A larger danger is the inappropriate use of scale. Fig. 3-5 shows a comparison of milk production for several cows in a dairy herd. At a quick glance, we might conclude that cow no. 232 produced less than half that of cow no. 583. When this figure is adjusted to the appropriate scale (by starting milk production at zero) as shown in Fig. 3-6, a much different picture of the relative levels of milk production appears. As a general rule, numerical scales should start at zero and each interval should be of equal size.

Placing data into categories and reporting the frequency of items for each category derives counts. *Frequency distributions* (also termed *tallies*) are the simplest form of a count as they represent the relative occurrence of values within given intervals for a variable. Fig. 3-7 shows a frequency distribution of lactation numbers within a dairy herd. *Cross-tabulations* are frequency distributions in more than one dimension. The simplest form of a cross-tabulation is a 2 × 2 table as shown in Fig. 3-8. In this figure, animals are classified into four groups: diseased and vaccinated, diseased and not vaccinated, healthy and vaccinated, and healthy and not vaccinated. A danger inherent in using count-based summaries occurs when quantitative data are "collapsed" into categories by selecting "cut-point" values.

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Command : MONITOR

#	Parameter	8 6	9 3	10 1	1029	1124	1130	1226	121	217	317	414	Goa
1	INVENTORY												
2	Total Cows/Herd	1914	1900	1907	1917	1951	1955	1991	2009	2035	2031	2042	
3	% Milking	85	86	85	85	85	85	86	86	87	87	89	8
4	% Heifers	34	32	32	31	31	31	32	33	33	32	33	
5	# Fresh Cows	123	141	109	129	100	11	124	111	107	125	99	
6	# Fresh Heifers	29	36	46	40	56	3	64	80	55	71	87	
7	# Dried	119	130	132	124	93	0	108	117	102	113	65	
8	REPRODUCTION												
9	Dimfb	67	65	64	64	64	68	66	71	69	66	67	6
10	% Bred by 70d	80	79	84	89	83	87	90	86	87	82	82	7
11	% PG at exam	66	63	67	64	69	0	77	69	73	75	77	8
12	Avg Heat Intvl	31.8	31.1	28.8	28.6	29.7	28.1	27.2	28.1	29.8	26.6	27.5	30.
13	# Aborts	17	11	19	11	4	0	10	10	11	10	12	
14	% PG by 168-195	63	61	54	50	51	50	60	63	63	58	75	7
15	%>150 DOPN/PG	24	25	25	25	28	28	28	28	29	28	26	2
16	FSC	29	24	25	23	20	0	26	27	27	38	39	3
17	3rdSC	60	57	54	54	54	0	63	69	69	80	80	7
18	# fresh recheck	0	1	0	0	0	0	2	0	2	0	2	

MONITOR 4/14/99 D:\DC305\COWFILE1.DAT Cow and Heifer File OFF

FIG. 3-4 DairyCOMP 305 herd monitor report. An example of a numerical report.

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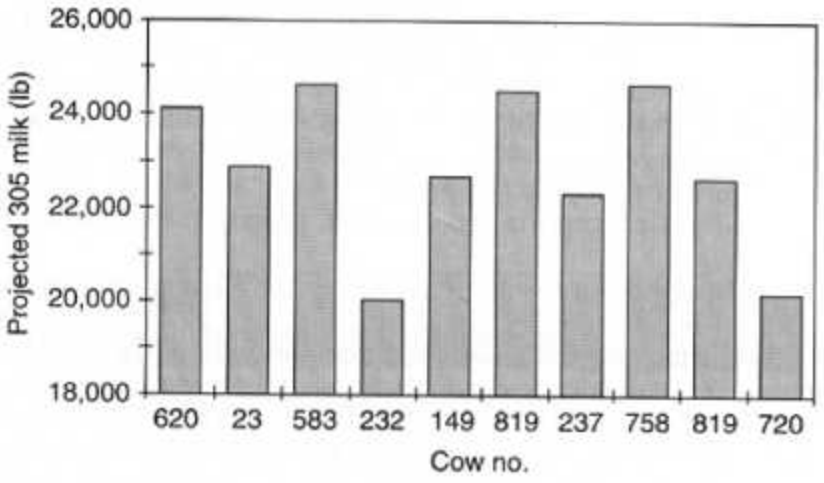

FIG. 3-5 Example graphical report with inappropriate scale.

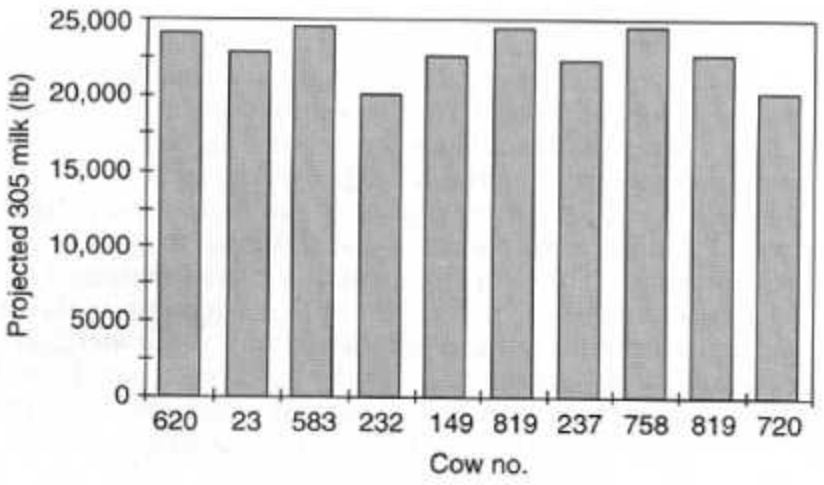

FIG. 3-6 Graph presented in Fig. 3-5 redrawn with appropriate scale.

Care must be taken when doing this, since this approach leads to a loss of power (the ability to detect an effect given that one exists). For example, the veterinarian could convert the ages of cows in a herd from the actual age to the categories young (less than or equal to 3 years old) and old (greater than 3 years old) for use in a 2 × 2 table. However, there is now no longer a difference between a cow that is 10 years old and a cow that is 4 years old. If an important effect occurred for animals more than 6 years old, the veterinarian would be less likely to detect it. For this reason, it is imperative to choose cut-points with biological significance, such as first-lactation heifers versus second lactation or higher.

A second potential problem with count summaries occurs when absolute numbers are compared instead of proportions (termed "dangling numerators"). For example, suppose a veterinarian tallied the number of mastitis cases for each lactation number in a herd and found that heifers had more mastitis. He or she may or may not be able to conclude that heifers were at higher risk depending on what proportion of the herd (both healthy and having mastitis) was heifers. Thus any comparison of characteristics of an animal must be expressed in terms of the appropriate denominator (e.g., expressed as a rate).

Numerous statistical measures exist and may be used in record analysis. The strength and weakness of statistical analysis are its narrow and specific interpretation (Wheeler and Chambers, 1992). Although the assumptions specific to each statistic give more power in "sifting through the chaff," if these assumptions are not appropriate, they may hide important features of the data. It is the inappropriate use of statistics that has led to the quote, "There are lies, damned lies, and statistics" (Huff, 1954).

A *scatter-plot* is a graphical summary of the relationship between two variables with one variable on the vertical axis and the second on the horizontal axis. Scatter-plots commonly consist of two continuous variables (variables that may take on any value within a range). A common adaptation of scatter-plots used in record systems is to define cut-points for one or both variables to divide the graph into quadrants as shown in Fig. 3-9. A scatter-plot with cut-points is analogous to a numerical cross-tabulation report and has the same problems associated with collapsed data and dangling numerators.

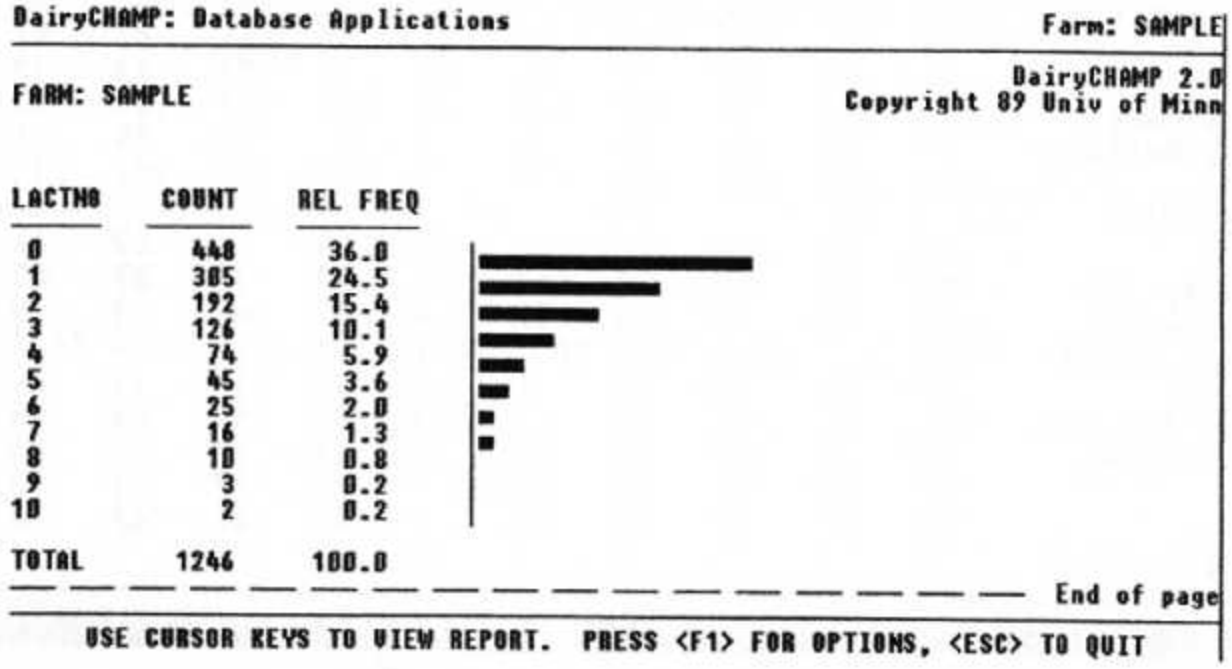

FIG. 3-7 DairyCHAMP frequency distribution and histogram for lactation number.

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	Diseased	Healthy	
Vaccinated	27	35	62
Not vaccinated	15	22	37
	42	57	

FIG. 3-8 Cross-tabulation of vaccine status by disease status.

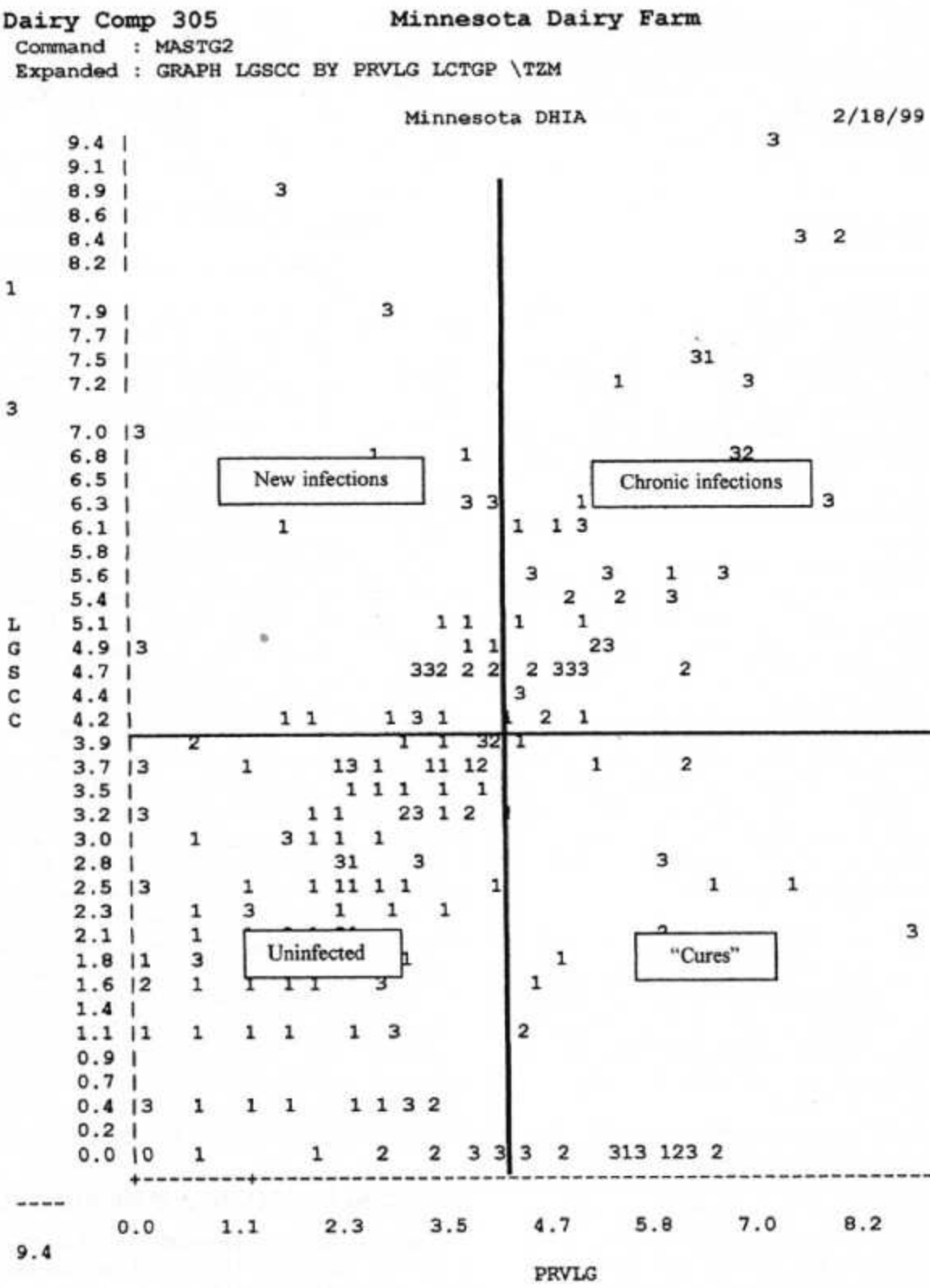

FIG. 3-9 DairyCOMP 305 somatic cell count scatter-plot of the most recent Dairy Herd Improvement (DHI) linear scores (y-axis) and last month's DHI linear scores (x-axis) with cut-points at a linear score of 4.0. *LGSCC*, Current log2 SCC; *PRVLG*, previous log2 SCC; *SCC*, Somatic cell count.

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A *histogram* is a graphical summary of data with possible values divided into categories (intervals) on one axis (normally the horizontal axis) and the frequency of values in these categories on the other (Wheeler and Chambers, 1992); it is analogous to the frequency distribution (Fig. 3-7). General guidelines for histograms are using equal-sized intervals, choosing endpoints where there is no uncertainty about where borderline values belong, and using 10 to 15 intervals, more or less, as appropriate (Wheeler and Chambers, 1992). A feature of the histogram is that it obscures sequential information such that care should be taken in using histograms with time-related data.

Time series plots, also known as running records, are plots in which values are shown on one axis (the vertical axis) and the time-order sequence is shown on the other. Hence the running record is a representation of a process over a period of time. The running record and the histogram can be thought of as complementary figures; the histogram collapses all the data to show the overall shape, whereas the running record stretches out the data to show the sequential information that is not apparent in the histogram (see Fig. 3-15). Special adaptation of the running record is the statistical process control chart and the *Kaplan-Meier survival curve* described in later sections.

Record Use in Herd Investigation

Herd investigation is a fundamental component of production medicine programs. Despite all best efforts, problems do occur in livestock operations. Many practitioners feel uneasy with the prospect of delving into a formal record/problem investigation, but the diagnostic skills are the same as those used in individual animal cases. The key to any successful diagnostic effort is to have a standardized, stepwise approach. A standard procedure makes practitioners less likely to miss something, generates as much information as possible to analyze, and makes it easier to check for any mistakes that may have occurred.

The goal of herd investigation is to identify management changes that will resolve the problem, not just to identify the problem. Two concepts are important to understand the rationale for this approach. First is the concept that all disease or suboptimal performance is multifactorial and that there are multiple ways that a given problem may occur. The second is the concept of a sufficient cause. A sufficient cause is the combination of risk factors (also called component causes) that produce the problem each and every time. A sufficient cause can be thought of as a pie with multiple pieces (component causes), and that multiple sufficient causes may exist for a given problem. Fig. 3-10 shows a hypothetical example from a diarrhea problem in calves with five component causes.

The goal of the investigation, in the context of the "pie" analogy, is to try to identify and eliminate at least one piece of the pie to prevent the completion of a sufficient cause. The "slices" of the pie are identified in two general ways: (1) by identifying management changes associated with the initiation of the problem and (2) by comparing affected animals with unaffected, at-risk animals.

Currently, there are no record programs that have all of the required features to conduct a comprehensive problem investigation, so some hand calculation is needed. The five steps that should be followed in a herd investigation are shown in Box 3-1. Remember, the goal of this protocol is to identify key determinants (risk factors that are under management control) as potential points of intervention. In addition, the herd investigation protocol should be used as a supplement, not replacement, for standard diagnostic methods.

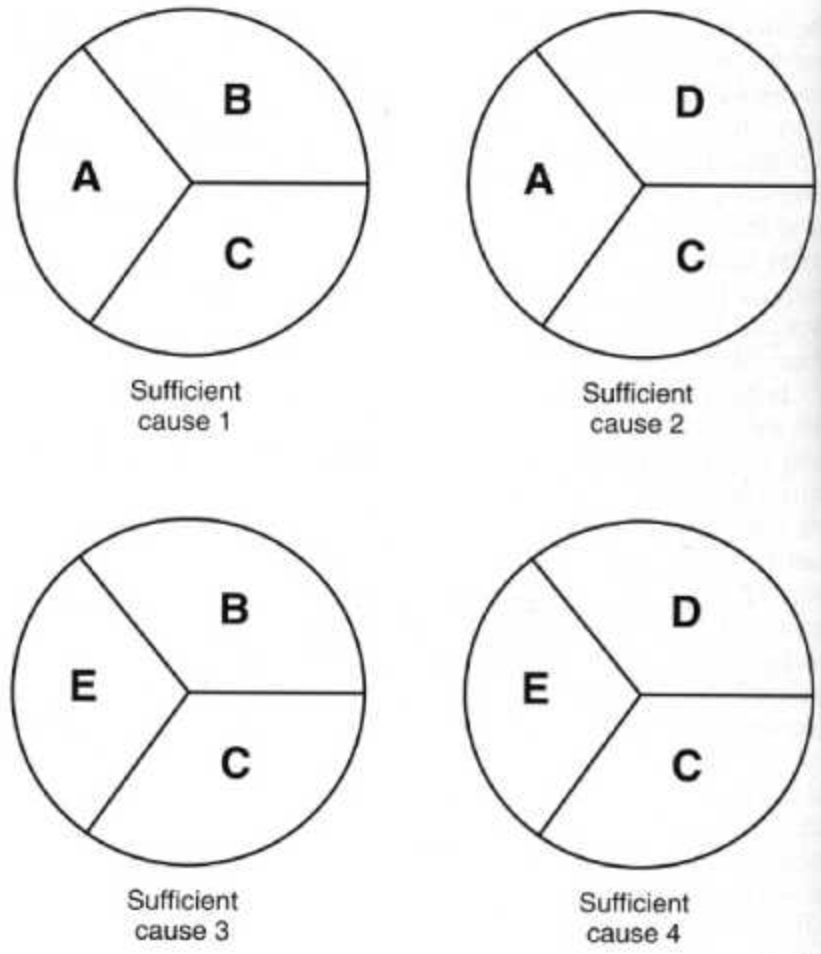

FIG. 3-10 Hypothetical sufficient causes for *Escherichia coli* diarrhea. *A,* Lack of passive transfer; *B,* stress from the environment; *C,* presence of *E. coli* 0157:H7; *D,* presence of second pathogen; *E,* malnutrition. (Adapted from Martin SW, Meek AH, Williberg P: *Veterinary epidemiology,* Ames, 1987, Iowa State University Press.)

Confirming the Problem

The first step in investigating a herd problem is to confirm that a problem exists and to what degree. Determining that a problem exists requires deciding on a case definition, deciding on the population at risk, and deciding the time frame of interest. The requirement of a case definition is necessary because in herd level problems, there are multiple animals involved with differing severity of the problem. Thus it is imperative to establish, *a priori,* some method to classify animals as cases, controls, or not at risk. For example, a dairy client asks a veterinarian to investigate a respiratory disease problem in his heifers. What constitutes a diseased heifer? Is a heifer that has a rectal temperature of 39.1° C (102.5° F), slightly increased lung sounds, but no nasal discharge, a case? Having a clear case definition is important.

Once the criteria have been established for classifying an animal as a case, the next step is to determine what the population at risk is and the timeframe of interest. This is necessary to define the unaffected, at-risk control for the case-control analysis. For the respiratory disease example, the population at risk would be heifers in the dairy during the period of interest. Determining the extent of the problem is then a matter of summarizing the number of animals at risk that became cases during the timeframe of interest.

Collecting Herd Data and Animal Information

Collect Animal History for Case-Control Analysis. Once the extent of the problem has been determined, a basic set of information is gathered concerning each case for later use in the case-control analysis. This data set should include information regarding all potential risk factors. Common risk factor categories include animal age, location,

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BOX 3-1

Herd Investigation Protocol

CONFIRM THE EXISTENCE AND EXTENT OF THE PROBLEM
Develop a case definition
Determine the population at risk
Determine the time frame of interest
Determine the proportion of at-risk animals that became cases during time frame of interest

COLLECT HERD DATA
Collect animal history for case-control analysis
Administer management questionnaire
Create farm event listing
Collect bulk tank shipment and milk quality data

SUMMARIZE HERD DATA INTO STANDARD FORMAT
Create farm event temporal plot
Create production history (e.g., bulk tank) temporal plot
Perform case-control risk factor analyis

COLLECT RISK GROUP–BASED SAMPLES

MAKE MANAGEMENT RECOMMENDATIONS

level of production, reproductive status, vaccination history, treatment history, and feed groups.

Management Questionnaire. The second set of information that needs to be collected is data concerning the management policies of the dairy. This can best be accomplished by administration of a management questionnaire. The questionnaire serves three functions: it allows comparison of management influences between farms, it structures questioning such that specific topics are not forgotten, and it serves as a measure of policy compliance. Topics that should be included in the survey include general information (farm ID, location, etc.), information concerning new animal arrivals, vaccination history, housing management and facilities, reproductive management, grouping of animals, nutritional management, and waste management and sanitation.

Farm Event Listing. The next step of the investigation should focus on creating a farm event listing. This document is a written record of farm-wide events listed by date of occurrence (Table 3-12). Events that should be recorded are the date of entry of animals from outside the farm, the date of feed changes, the dates of whole herd vaccination, previous episodes of illness, and any herd-wide management changes. Farm events are things that affect the entire herd regardless of herd size. Therefore information collected for this farm event listing should go back at least 6 months before the start of the problem, if possible.

Record of Product and Performance Output (i.e., Bulk Tank Shipments and Milk Quality Reports). The last set of data to collect on a dairy farm is a record of the bulk tank shipments and milk quality reports. Evaluation of this information may provide evidence of a date of exposure to the inciting event. It is important to remember that shipping weights alone must be carefully interpreted in light of the number of cows contributing to the tank and that the average production per cow is a much better measure of milk production. Daily variation in milk production may be smoothed using a 10-day moving average. Data should be collected for at least 6 months before the first case of disease.

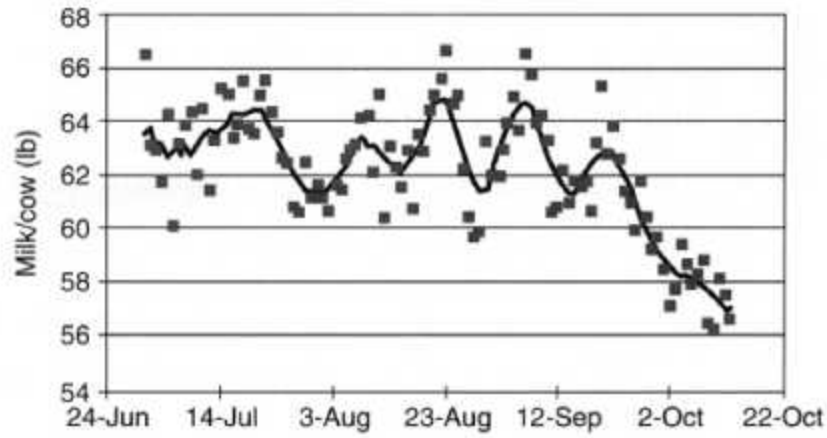

FIG. 3-11 Example of bulk tank shipment temporal plot.

TABLE 3-12

Example of a Farm Event Listing

Date	Farm event
04/12/99	Started feeding alfalfa stack #1
04/26/99	Vaccinated whole herd for leptospirosis
05/06/99	Started feeding alfalfa stack #1
05/12/99	Hired new feeder
05/15/99	Bought load of 17 springers from auction
05/27/99	Started feeding corn silage
06/01/99	First abortion of cluster
06/17/99	Vaccinated whole herd for leptospirosis

Fig. 3-11 shows a graph of the bulk tank shipments for a dairy with a significant drop in production starting in late September. Further investigation found that the dairymen had started feeding a low-quality haylage in August. The dairy also initiated the use of bovine somatotropin (bST) in August, causing the impending drop in production to be delayed. Following "disappointing" performance of the bST, the product was discontinued and the production drop occurred.

Summarizing Herd Data into a Standard Format

Create Farm Event Temporal Plot. The first data processing step is to create temporal plots of the farm event listing and bulk tank data. These graphical depictions of events allow juxtaposition of the problem history with farm level events or changes in production that can provide valuable insight into events that may be associated with the onset of the problem. Plotting of farm events is most easily performed using a horizontal bar graph with each type of farm event listed on the y-axis and time plotted on the x-axis. Events that occur on a single day are best represented by a symbol such as an "X." Abortion cases are best plotted as the first row above the x-axis. Using this arrangement, the investigator can scan for vertical associations of farm events with the start of the abortion problem. A hypothetical farm event temporal plot is shown in Fig. 3-12. This dairy used three different forages before the outbreak, vaccinated the whole herd 36 days before the outbreak and 16 days after, purchased 10 new springers 17 days before the outbreak, and hired a new feeder 20 days before the outbreak. Possible

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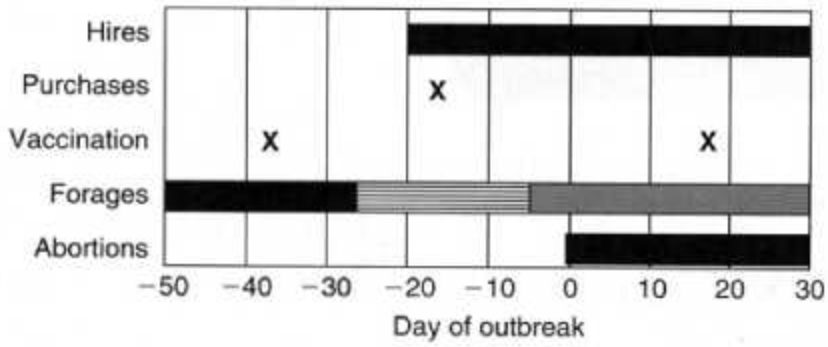

FIG. 3-12 Example of farm event temporal plot.

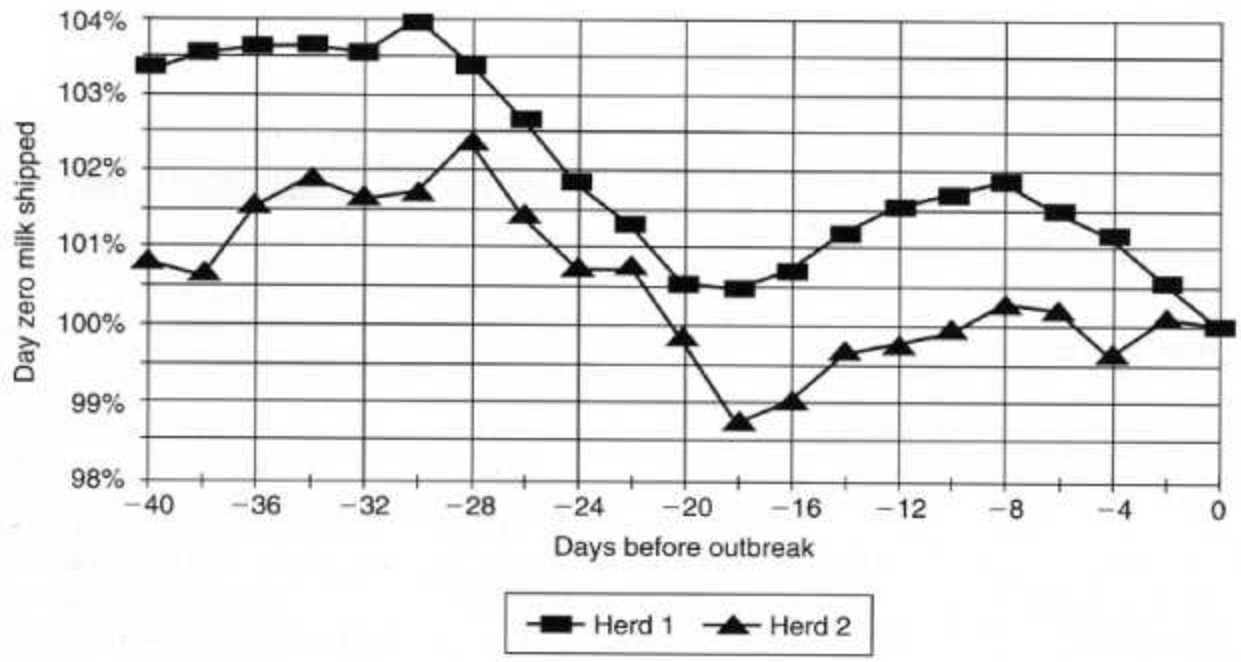

FIG. 3-13 Bulk tank milk shipments for two dairies before *Neospora* abortion outbreak.

sources of the problem are the new feed, the new feeder, and the purchased springers.

A temporal plot of bulk tank data can be constructed in a similar manner with moving average milk production, fat, protein, and SCCs plotted against time. Fig. 3-13 shows a bulk tank milk shipment temporal plot from two *Neospora* abortion outbreaks. Milk production has been standardized to a percentage of day 0 production to allow comparison across herds. Notice how there is a biphasic pattern with the initial drop approximately 30 days before the outbreak and a second decline the week before the outbreak. Further questioning of the herd managers on these dairies identified a change to a wet feed associated with the initial drop, suggesting the possibility of these *Neospora* outbreaks being initiated by a cofactor.

Case-control comparison. After construction of temporal plots, a matched case-control analysis is performed. The concept of a case-control analysis is to identify what is different about animals that developed the problem compared with animals that did not but could have. Thus the idea in selecting controls is to choose animals that would have developed the disease given they had all the risk factors. Selection of controls is a three-step process. *Step one* is to make a table of all cases by month of the variable of interest. For example, in abortion investigation, cases are listed by month of conception. For postpartum cow problems, cases are listed by month of calving. This cohort approach enables removal of any effects relative to changes in the environment (i.e., weather differences, feed changes). *Step two* consists of making a similar table of all cows that were at risk but did not have the problem using the same monthly cohort (e.g., month of calving). In *step three* each case cow is paired with a randomly selected control cow from the same monthly cohort. Thus there should be one control for each case and the same number of controls from each month as there are cases.

After the controls have been selected, the core information recorded earlier for each case should be recorded for each control (for more information on the proper selection of controls, see Rothman, 1986, or Martin, 1987). Data from cases and controls are then used to create 2×2 tables similar to Fig. 3-14 for analysis of the proportion of cases (and controls) found in each risk group. From this 2×2 table, an odds ratio may be calculated (as shown in Fig. 3-14).

The odds ratio represents the odds of disease for animals in the top row of the table (defined as animals with the risk factor) relative to the odds of disease for animals in the bottom row (defined as animals without the risk factor). For example, if the top row refers to animals more than 3 years old and the bottom row refers to animals 3 years old or younger, an odds ratio of 2.0 means that the older animals are 2.0 times more likely to get the disease than the younger animals. Fig. 3-14 shows example data from a field trial investigating the relationship between problem cows (cow with postpartum problems) and the subsequent development of fever. In this example cows with problems are 2.04 times more likely to develop a fever later in lactation.

Notice that the odds ratio by itself does not provide any indication of the actual disease frequency; it would be the same if 50% of the old and 25% of the young were diseased,

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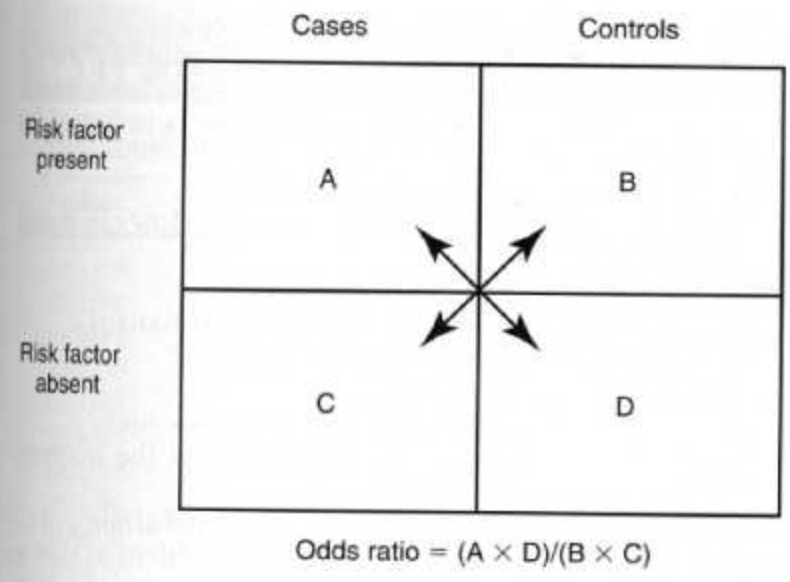
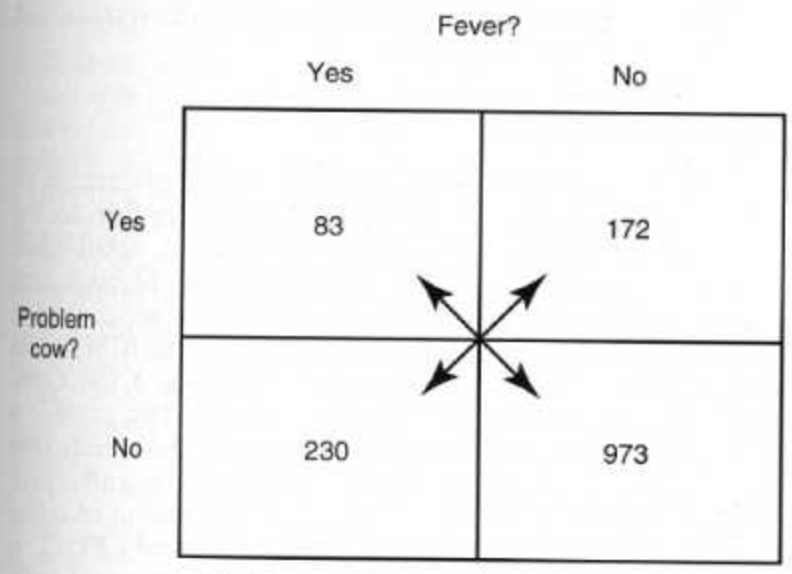


Odds ratio = (A × D)/(B × C)



Odds ratio = (83 × 973)/(172 × 230) = 2.04

FIG. 3-14 Two-by-two setup with odds ratio calculation. The example field trial data show an odds ratio calculation. Cows with a postpartum problem are 2.04 times more likely to develop fever later in lactation.

or if 5% of the old and 2.5% of the young were diseased. It just indicates the *relative* frequency.

So what does it mean if the odds ratio is less than one? Many times as practitioners set up a table, they may not know if the factor they put on the top row is related to an increase in disease risk or not. In the case in which the odds ratio is less than one, the risk factor chosen for the top row is actually protective (i.e., animals with this characteristic are at less risk). In this case, the practitioner could invert the odds ratio and list the bottom row as the risk factor. For example, suppose the practitioner constructs a table with old cows as the top row and young cows as the bottom and the calculated odds ratio is 0.5. This finding can be interpreted as old cows being 0.5 times as likely to develop this disease, or as young cows being 2.0 (1 divided by 0.5) times more likely to develop the disease.

As a general rule of thumb, odds ratios greater than 2.0 (or less than 0.5) are considered fairly large. It is important to note that statistical testing is not being used in this approach—just the strongest relationships. For example, suppose a veterinarian is investigating a disease outbreak in cattle, and the odds ratio for old versus young cattle was 1.9, the odds ratio for fat versus thin cattle was 2.3, and the odds ratio for pasture 1 versus pasture 2 was 14.0. The veterinarian really should be curious about how pasture 1 differs from pasture 2. When using this approach, always be cognizant of the biological plausibility of these relationships. Just because a "large" odds ratio is found does not necessarily mean that this relationship is important in the disease progression. At times a mathematical relationship will be found (statistical significance) by chance that does not represent a true relationship for the progression of the disease (biological significance). Whether a large odds ratio is biologically significant should be determined by current circumstances and sound medical principles.

Risk group–based sampling. The last step in investigating problems in livestock operations is to collect laboratory samples based on risk groups. This risk group–based sampling has two benefits. First, it allows comparison of case animals to animals in other risk groups for changes in laboratory values. Second, it will increase the total number of samples submitted, which increases the likelihood of identifying the source of the problem. An example risk group sampling protocol for a dairy herd abortion investigation would be to bleed animals for serology in the following groups: cows that have aborted (at risk, affected), cows that are pregnant but did not abort (at risk, unaffected), and cows that are not pregnant (not at risk). It is important to remember that at least 10 samples should be collected from each risk group if possible to ensure adequate sample size for comparison across risk groups.

Management recommendations. It is important that no management changes be made on the farm at the time of the problem investigation. It is best to first combine the results of the investigation protocol with the results of the laboratory testing to obtain a clearer understanding of the total picture before making final recommendations. It is wise to implement only a few of the management changes at any one time so that both positive and negative effects can be more easily determined. Finally, it is absolutely essential to designate an appropriate monitor for each recommended change so that success or failure of the recommendations can be measured.

Advanced Record Analysis Techniques

Statistical Process Control

"SPC (statistical process control) is a way of thinking with charts acting as a catalyst for this thought process" (Wheeler and Chambers, 1992). SPC is one of the most powerful tools for process improvement. However, unless SPC is used as a part of a production system in which the idea of continuous improvement is embraced, it is just another way of representing data in a graph (Polson et al, 1999). It is important at the onset of this discussion to emphasize this point. Experience has shown that application of SPC without commitment to the continuous improvement concept will not be a very productive or satisfying experience. SPC is not new, having been used successfully in manufacturing businesses for over 70 years. SPC has not been extensively used in animal agriculture. SPC was first tried in swine production over 20 years ago (Wrathall, 1977). However, the principles of SPC are proven, and use in animal agriculture is merely a shift of application to a biological production system. Although the biological system is more variable and thus presents a greater challenge, there is great optimism that SPC techniques will become another valuable tool for livestock monitoring (DeVries et al, 1997; Polson, 1998; Polson et al, 1999).

How great a deviation from "normal" constitutes real change? Is this change sufficient to merit the expense and effort of the recommended intervention? Sometimes the decision is a "no brainer," but too often neither the practitioner nor the client is really sure. It is this lack of confidence that

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may weaken the practitioner's resolve to insist that action be taken as well as erode his or her client's commitment to take seriously the recommendations and initiate timely corrective action.

Each time practitioners face this sort of dilemma, they are in danger of making errors in interpretation. When random variation (common cause variation) is mistaken for a real change in cow productivity or health, veterinarians may diagnose a nonexisting change (Type I error or false positive). Application of unnecessary corrective action truly would be a waste of labor, time, and money. Such action detracts from productive management. It adds complexity and creates management chaos. On the other hand, failure to identify an emerging problem quickly enough to initiate timely corrections (Type II error or false negative) is also a great concern. The indecisive strategy of "let's wait to see what it looks like next month" may squander the opportunity to nip the problem in the bud. Furthermore, subtle changes could go undetected for months, creating a deep-seated herd problem.

SPC is a set of several analytical tools of which the control chart is an important one. This discussion focuses only on control charts. Control charts are helpful in signaling that a true change has occurred. The fundamental concept of control charts is to distinguish between inherent random variation and real changes in output, quality, or measured performance. Properly applied control charts can prevent the misinterpretation of inherent random variation because of "common causes" of variation. More important, they provide a timely signaling of real change because of "special cause" variation. Common causes affect all data and are chronic, stable, and predictable within limits. Special causes affect some data and are sporadic, unstable, and unpredictable. SPC methods can be used to signal emerging problems and evaluate the positive or negative impact of a change in a management practice or the implementation of a new product.

Typical livestock management reports provide a plethora of data, usually in tabular form. The inevitable result of having such a large volume of data presented in such a small area is that it requires much study and effort to interpret. The human mind does not do very well absorbing large amounts of data. In addition, most veterinarians tend to be numerically illiterate (Wheeler, 1993). It is not that they do not understand the mechanics of arithmetic. Rather they do not intuitively know how to extract knowledge from data. The most common use of livestock management data is to compare this month's average with last month's average. Are they doing better or worse? The problem with such limited comparisons is that they are out of context. Context here means that the data should be interpreted in context of the time order in which they were generated. Context also means that the natural variation in the data and its relationship with similar data generated by the process must be taken into consideration.

Data divorced from their context can be misleading. Although several months of tabular data would provide ample context, most people find it difficult to assimilate and provide accurate interpretation. For example, consider the relatively simple table of daily bulk tank somatic cell count (BTSCC) data for a Minnesota dairy (Table 3-13). Looking at the table, readers might ask a few simple questions to aid in interpretation:

- How were the data collected and calculated? By whom?
- What is the highest value? The lowest? The average? The median?
- What is the normal, day-to-day level of variation?
- What causes the normal variation?
- When is variation abnormal?
- When should veterinarians be worried?
- How does this herd compare to other herds?
- Is there potential for improvement? How much?
- Is intervention worth the cost?
- Does this herd currently have a problem as indicated by the BTSCCs?
- Have there been problems in the past?
- Is mastitis management "under control"? How can someone tell?
- If mastitis were to go "out of control":
  - –How soon would these data tell the veterinarian?
  - –How quickly would the veterinarian react?
  - –What would the veterinarian do?
  - –How would the veterinarian measure response?
  - –Would the veterinarian be confident that the intervention had made a difference?

Obviously study of tabular data is overwhelming, time consuming, and often unproductive. The problem of how to analyze tabular data is depicted in the statement of a busy veterinarian: "I don't have time to study all the records, just give me the abridged version."

Time Series Charts

Since people are visually oriented and tables of data are visually boring, graphs make data more accessible to the human mind. Graphs can remove extraneous detail while providing context for visual interpretation. Management data usually have a time order. Therefore a time series chart of data improves interpretation. Consider again the BTSCC data for a Minnesota dairy in a time series chart (Fig. 3-15). Compared with the tabular format, the plotted data provide a much clearer idea of the BTSCC changes and trends over time. Practitioners can use their prior knowledge and experience of BTSCC data to form a general impression of udder health of this herd. They can see that this herd's BTSCC is generally too high with possibly a slightly upward shift. However, a simple time series chart does not have sufficient resolution for more meaningful interpretation. It is still difficult to identify subtle changes or to know if the BTSCC in this herd is "in control" or "out of control." This is because the inherent random variation (noise) masks real changes. Noise, like static on a car radio, makes listening annoying and difficult to understand. The Shewhart control chart is the simplest method to separate potential signals from probable noise.

Control Charts

In the 1920s Dr. Walter Shewhart at Bell Laboratories invented control charts to help interpret data that are generated over time. Control charts provide further insight into data by displaying the level of normal, random variation in the data and by revealing the observations that indicate real change. This approach affords the practical application of statistical theory in a visual, easy to interpret context. The steps to develop a Shewhart control chart are as follows:

1. Start with a time series chart.
2. Add a centerline (mean) for central reference.
3. Add control limits, computed from the data and based on the common cause variation only, equidistant on either side of the centerline.
4. Apply tests to distinguish between data points resulting from special causes and data points resulting from common causes only.

Control limits are calculated by two methods. One method uses standard deviation (SD), which is a common measure of variation. Experience has shown that 3 SDs away from the center line is a good balance between the number of false-positive signals (type 1 error) and false-negative sig-

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TABLE 3-13

Bulk Tank Somatic Cell Count (BTSCC) for a Minnesota Dairy (BTSCC × 1000)

Date	BTSCC	Date	BTSCC	Date	BTSCC
10/1/98	236	11/14/98	235	12/27/98	312
10/2/98	303	11/15/98	265	12/28/98	294
10/3/98	236	11/16/98	238	12/29/98	242
10/4/98	219	11/17/98	212	12/30/98	248
10/5/98	224	11/18/98	239	12/31/98	215
10/6/98	246	11/19/98	267	1/1/99	212
10/7/98	292	11/21/98	229	1/2/99	292
10/8/98	270	11/22/98	272	1/3/99	300
10/9/98	225	11/23/98	219	1/5/99	327
10/10/98	238	11/24/98	257	1/6/99	229
10/11/98	228	11/25/98	279	1/7/99	244
10/13/98	243	11/26/98	205	1/8/99	274
10/15/98	226	11/27/98	218	1/9/99	295
10/16/98	225	11/28/98	235	1/10/99	306
10/17/98	227	11/29/98	281	1/11/99	314
10/18/98	275	11/30/98	272	1/12/99	242
10/19/98	248	12/1/98	256	1/13/99	266
10/20/98	244	12/2/98	269	1/14/99	243
10/21/98	231	12/3/98	227	1/15/99	262
10/22/98	250	12/4/98	258	1/16/99	293
10/23/98	239	12/5/98	261	1/17/99	281
10/24/98	267	12/6/98	250	1/18/99	278
10/25/98	271	12/7/98	230	1/19/99	238
10/26/98	226	12/8/98	266	1/20/99	233
10/27/98	244	12/9/98	262	1/21/99	257
10/28/98	189	12/10/98	219	1/22/99	271
10/29/98	303	12/11/98	271	1/23/99	232
10/30/98	229	12/12/98	266	1/24/99	244
10/31/98	242	12/13/98	220	1/25/99	275
11/1/98	255	12/14/98	243	1/26/99	213
11/2/98	217	12/15/98	180	1/27/99	254
11/3/98	205	12/16/98	213	1/28/99	312
11/4/98	238	12/17/98	221	1/30/99	352
11/5/98	214	12/18/98	276	1/31/99	303
11/6/98	250	12/19/98	268	2/1/99	284
11/7/98	220	12/20/98	334	2/2/99	227
11/8/98	212	12/21/98	303	2/3/99	298
11/9/98	241	12/22/98	323	2/4/99	347
11/10/98	265	12/23/98	329	2/5/99	325
11/11/98	261	12/24/98	285	2/6/99	281
11/12/98	242	12/25/98	241	2/7/99	336
11/13/98	255	12/26/98	275	2/8/99	349

nals (type 2 error). The other method (mean range method) uses the mean of the values plus or minus the average range between values times a constant. The constant depends on the number of values within each subgroup and is looked up in a table. The mean range method gained acceptance historically because in the early years of SPC, calculation of SDs was difficult. Both methods are designed to give the same approximate answer. Today even relatively inexpensive hand calculators compute SDs. It should be noted, however, that the SD method is more prone to error when there is more than one subgroup of data being considered (Wheeler and Chambers, 1992). However, if calculation of control limits are done correctly, both methods result in nearly identical control limits as well as the same interpretation.

The resulting zone between the center line and 1 SD is called Zone C, between 1 and 2 SDs is Zone B, and between 2 and 3 SDs (the control limit) is Zone A (Fig. 3-16). These zones are important for applying the interpretive tests discussed later.

Control limits are calculated based on the data collected in a timeframe called the "control period." Experience has show that 20 data points are needed to calculate credible control limits (Wheeler and Chambers, 1992). When a practitioner initiates a control chart, it is appropriate to use the first 20 data points collected as the control period. Once control charting is established, the control period can be set depending on the question being asked. If the intent is to monitor a process for the purpose of maintaining a stable process, then using data from an apparently stable period makes sense. If the intent is to use the control chart to evaluate the introduction of a new product or a change in process procedure, for instance, then the control period should be

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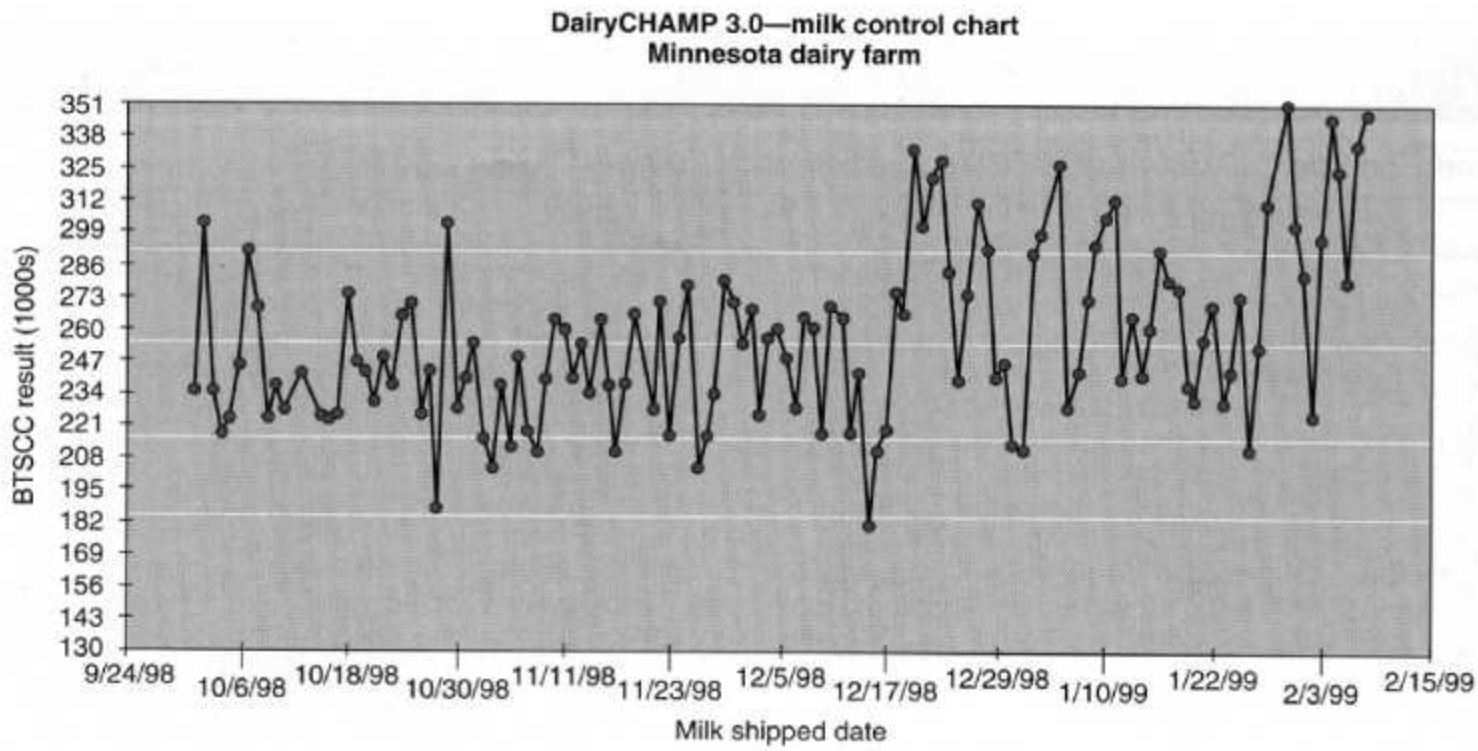

FIG. 3-15 Time series plot of the daily bulk tank somatic cell count (*BTSCC*) for a 200-cow Minnesota dairy. The upward trend is more apparent than the tabular data, but how certain could the practitioner be on December 18 that the processes contributing to BTSCC were "out of control"?

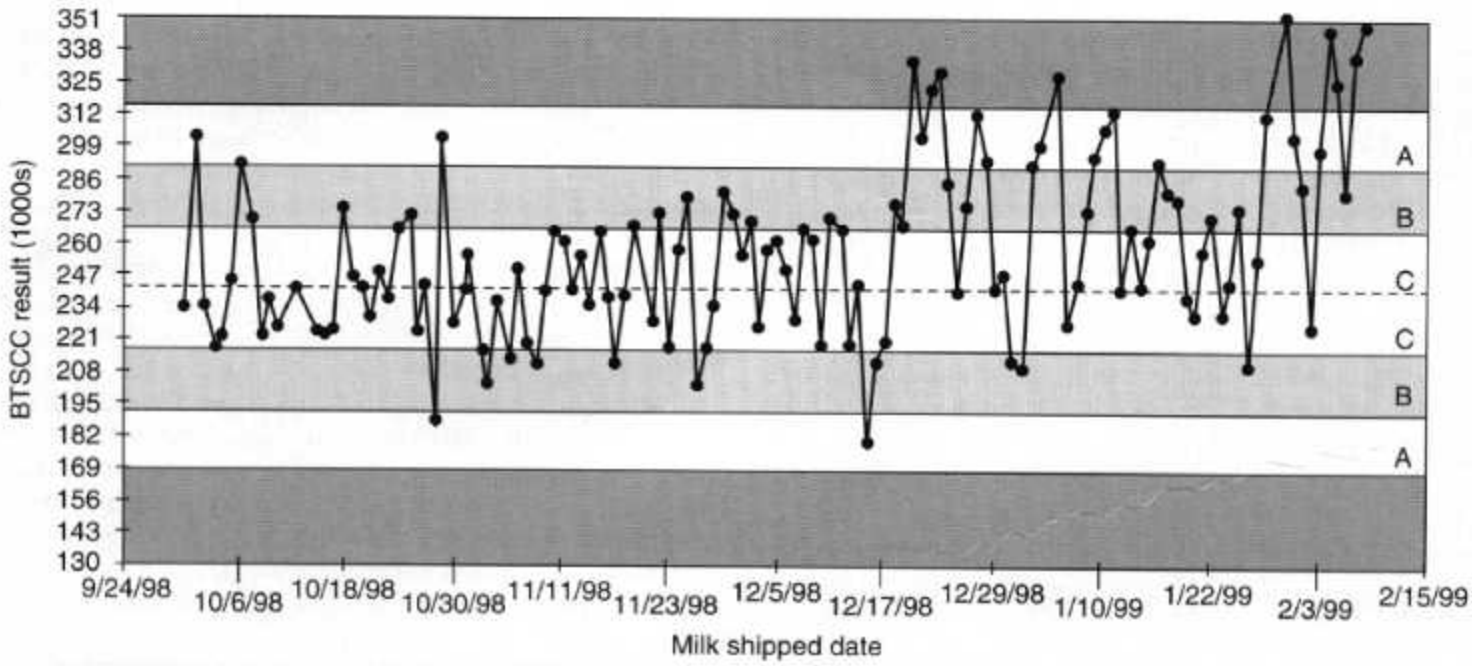

FIG. 3-16 Bulk tank somatic cell count (BTSCC) for a Minnesota dairy plotted in a Shewhart control chart. The mean and 3 standard deviations (zones A, B, and C) were calculated using the daily BTSCC data for the period from October 1, 1998, to December 1, 1998.

calculated from data collected just before the introduction of the product or change in procedure. The control limits for the example using the BTSCCs were calculated using the October 1998 to December 1998 BTSCC data, since there was no indication of special variation in that period; thus the process appeared to be "in control." Mean BTSCC for the designated control period was 243,000 and the SD was 24,300. Thus the limits for Zone C were 243,000 ± 24,300 (between 218,700 and 267,300). The limits for Zone B were 243,000 ± (2 × 24,300) (between 194,400 and 218,700 and again between 267,300 and 291,600). Finally, the control limits were calculated as 243,000 ± (3 × 24,300). Zone A, therefore, is between 170,100 and 194,400 and again between 291,600 and 315,900 (Fig. 3-16). Calculation of control limits using the mean range method gave the same results.

Note that the picture becomes more clear than a time series plot, but it remains difficult to interpret the data without a formal and standardized approach to distinguish between "normal" (common cause) variation and variation that deserves more attention.

Interpreting Control Charts Using Tests

Several tests exist that can help in the correct interpretation of control charts. When a single data point is observed out-

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side one of the control limits, the probability is that this point is not a real change (false positive) but is only 3 out of 1000. Seven additional tests use multiple data points to indicate, with a high probability, that a real change has occurred (Nelson, 1984). Using several tests simultaneously for signaling special causes increases the sensitivity of a control chart but also increases the possibility of a false positive. The combined probability that any of the eight tests indicate a "real change" when there is none is about 20 out of 1000, or 2%. Thus it is generally safe to assume that the process is "out of control" when any one of these tests indicates a change. The eight tests are as follows:

- Test 1: A single point outside one of the control limits
- Test 2: Nine points in a row on one side of the centerline
- Test 3: Six points in a row either all increasing or all decreasing
- Test 4: Fourteen points in a row alternating up and down
- Test 5: Two out of three points in a row in or beyond Zone A on either side of the centerline
- Test 6: Four out of five points in or beyond Zone B on either side of the centerline
- Test 7: Fifteen points in a row in Zone C on either side of the centerline
- Test 8: Eight points in a row on either side of the center line with none in Zone C

A simplified version of the eight tests has been used extensively in industry and is known as the Western Electric Zone Test (Wheeler and Chambers, 1992):

- Detection rule one: A lack of control is indicated whenever a single point falls outside the (three-sigma) control limits (Zone A).
- Detection rule two: A lack of control is indicated whenever at least two out of three successive points fall on the same side of, and more than two sigma units away from, the central line (within Zone A).
- Detection rule three: A lack of control is indicated whenever at least four out of the five successive values fall on the same side of, and more than one sigma unit away from, the central line (within Zone B).
- Detection rule four: A lack of control is indicated whenever at least eight successive values fall on the same side of the central line.

Wheeler (1993) summarized the aforementioned eight tests into three simple tests that he felt are adequate for most management situations. They are as follows:

- Test 1: A single point outside control limits
- Test 2: Three out of four consecutive points closer to the control limit than to the centerline
- Test 3: Eight or more successive points on one side of the centerline

Anytime the conditions of any one of these three tests are met, the veterinarian can be certain the process has changed and is by definition "out of control." Considering these tests as new data become available ensures timely signaling of real changes. Using Wheeler's three tests to detect special cause variation, the reader should reconsider the control chart of BTSCC data (Fig. 3-16).

Wheeler's second test indicates that starting on December 18, there is clear and significant upward shift in the level of BTSCC. The process is "out of control." There is no need to vacillate, since the practitioner can be 95% certain that the shift is "real" and it is not just normal variation. Since data should be interpreted in their context, these observations may or may not be a surprise to the dairy manager. For example, in this case the distractions of the Christmas holiday may have disrupted normal herd management. If this were the case, this may well explain the shift in BTSCC level. The control chart then confirms the expectation about the BTSCC level. However, if no explanation can be given readily, investigating the probable causes of the shift in BTSCC is well worth the effort and cost. There are two basic questions regarding a breakdown in the process:

- Is this a personnel management issue? (e.g., protocols not being followed)
- Is there some flaw in the process itself? (e.g., breakdown in equipment or an inadequate protocol)

For example, maybe the new employee does not do a good job scraping the stalls, or the replacement bedding material is contaminated. Control charts provide a means for early detection of "real" changes, providing the opportunity to nip the problem in the bud. In this particular case there was no action taken. As can be seen, the consequences resulted in further process entropy and obvious deterioration of those processes contributing to BTSCC level.

Control charts also offer a means to evaluate efforts toward continuous process improvement. Fig. 3-17 is a control chart of a large Wisconsin dairy that has kept its herd bulk tank count less than 200,000 for 20 years. During the period between January 1, 1999, through mid-February, the BTSCC was averaging 140,000 and was "in control." However, the herd manager felt that the herd BTSCC should be 100,000 or less, as had been the case during previous years. During the March 21, 1999, meeting with the milking parlor staff, a consensus was reached:

- That more attention be placed on premilking teat end sanitation
- That cows with extremely high SCC quarters be identified with a leg band so that the high SCC quarters could be milked into a quarter bucket

The plan was implemented immediately. Did the program work? Study of Fig. 3-17 clearly indicates a dramatic and significant decline in herd BTSCC. Wheeler's second test indicated that by March 26 the herd manager knew with 95% certainty that the plan was working and could use the chart as positive feedback to the parlor crew to reinforce their dedicated effort.

Control charts are not intended for retrospective use. The whole philosophy of SPC is geared toward proactive, continuous improvement. However, Fig. 3-18 is a control chart plot showing severe butterfat depression, which was plotted retrospectively. A similar plot of the milk protein over the same period as well as study of individual cow DHI test day data indicated a profound fat-protein inversion. University extension specialists had been asked to help this herd recover from an episode of severe butterfat depression and rumen acidosis. The control chart was used to help pinpoint the time when the problem began and validate the triggering cause. Had this herd manager or the herd nutritionist been more vigilant, and had they been using a control chart to monitor bulk tank milk components, the whole unfortunate episode might have been avoided. New corn silage was introduced to the herd on September 13, 1998, without appropriate adjustments in the diet. Note that by September 17, 1998, the cows were sending a clear signal that something significant in the diet had changed. A timely correction could have avoided the serious harm and economic losses caused by this unfortunate incident.

Control charts are commonplace in the manufacturing and service industries. They have great potential for improved decision making in livestock management. Monitoring BTSCC with a Shewhart control chart is a good example of a valid application. Plotting of frequently collected individual data in a control chart (i.e., daily feed intakes, daily milk weights, milk components including milk-urea nitrogen) is the simplest of SPC techniques. Pigs weaned per breeding female, percent mortality, piglets born dead, and average daily gain are examples of data from production groups (cohorts), which in large operations are started on a

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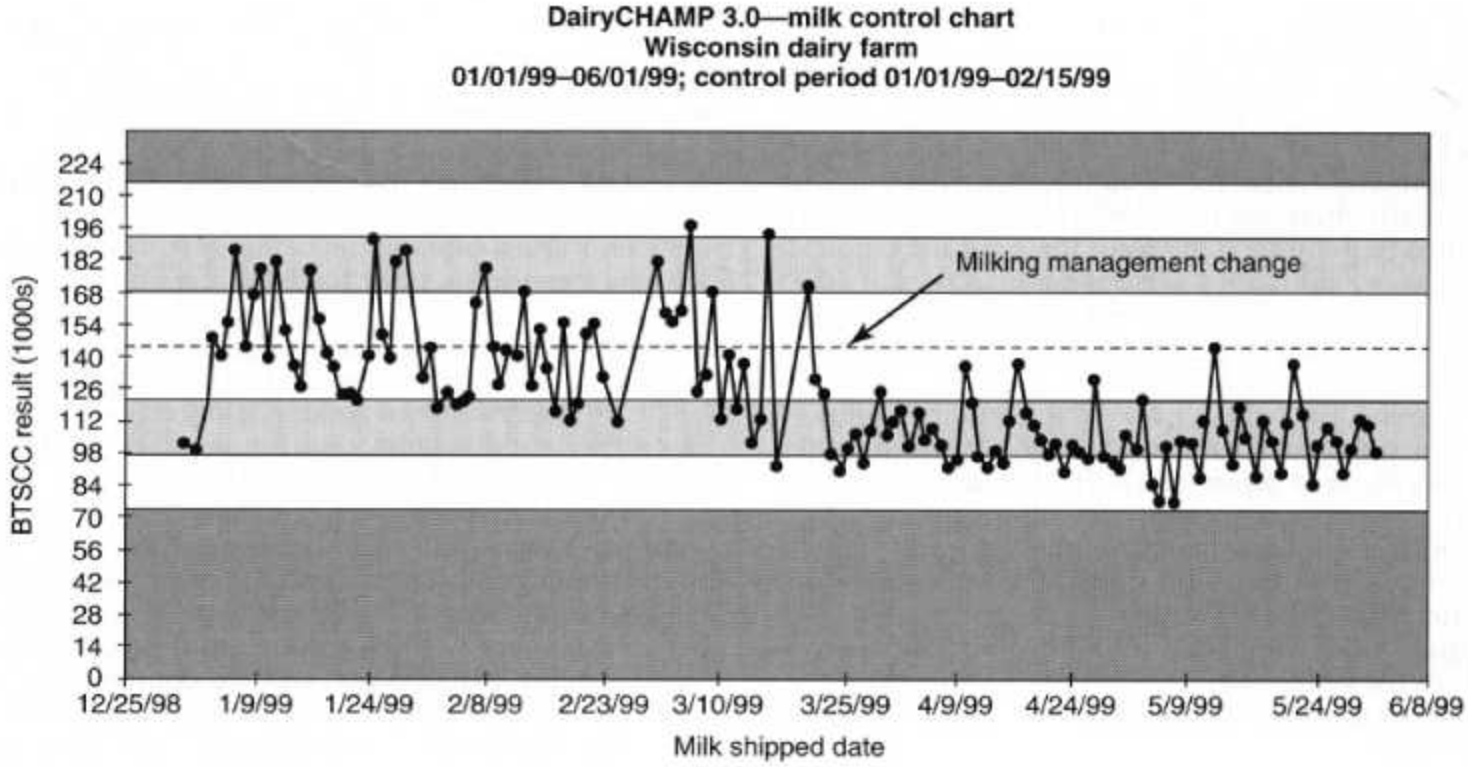

FIG. 3-17 Shewhart control chart of daily bulk tank somatic cell count (BTSCC) on a Wisconsin 700-cow dairy. Control chart use allowed the herd manager to know with certainty on March 26, 1999, that the changes in parlor management implemented March 22, 1999, were working.

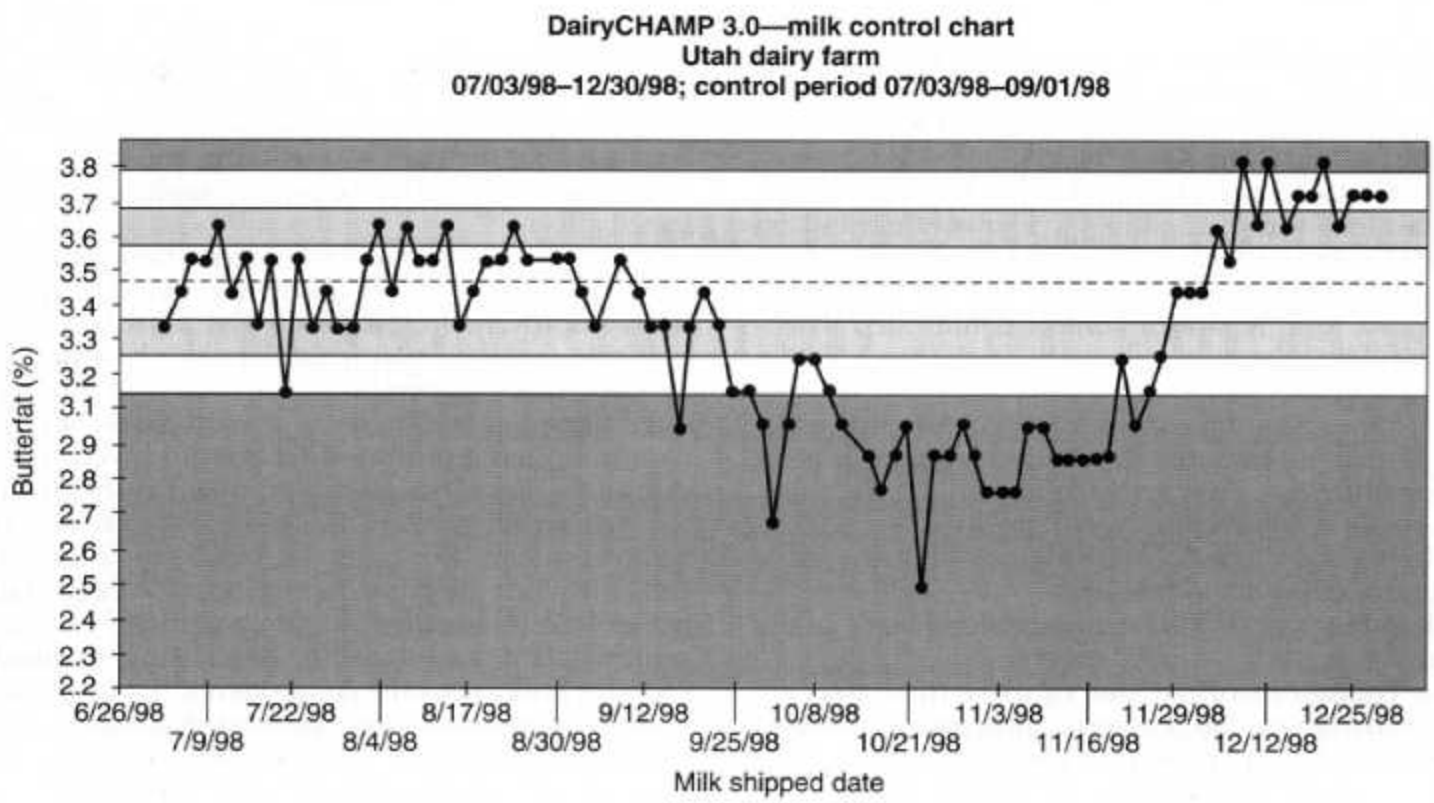

FIG. 3-18 Shewhart control chart of daily bulk tank butterfat percent in a herd with severe butterfat depression. The earliest signal that things were "out of control" appeared within a few days after the ration change, which precipitated the rumen acidosis.

frequent enough basis for possible use of SPC techniques. There is still much research work to be done in confirming which variables are appropriate for SPC applications. Generally data suitable for SPC application are the following:

- Data that are easy and practical to collect
- Data collected on a frequent basis (daily, weekly) are preferable
- Data of economic significance
- Data that, as directly as possible, reflect process behavior

Besides monitoring the mean of a process, the range of the data points can also be monitored. When individual raw data are averaged into subgroups of data (e.g., weekly BTSCC averages, piglets born dead, pigs weaned per cohort of breeding females), it would be necessary to monitor both

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the mean and the range to adequately detect "signals" caused by special cause variation. These methods can be extended and refined to a greater degree; for example, the sensitive CUSUM can be used to detect small shifts in the process mean. A CUSUM is a cumulative sum of deviations from a prediction or target. At present more study is needed to determine the appropriateness of applying all of the SPC techniques in monitoring livestock production systems.

Although SPC and the use of control charts are useful monitoring tools, there are pitfalls. The greatest pitfall is initiating SPC techniques without the right mindset. If these techniques are attempted where management is not willing to embrace the philosophy of continuous improvement, they will inevitably fail to produce anticipated results. Another pitfall is improper calculations of control limits, which as was previously mentioned results in too many false signals. However, these techniques are robust and when used appropriately are effective herd monitors. It is expected that SPC will play a major role in livestock monitoring in the future.

Cohort-Based Analysis

The term "cohort" comes from the Roman word for "group"; cohort-based analysis is record analysis based on common groups. These cohorts may be groups based on location, production, or, most commonly, stage of lactation. The advantage of cohort-based analysis is that animals are already managed in groups such that deficiencies identified for any specific group represent a common problem at a common time; this problem may be directly addressed through a management change. A good place to show the differences between conventional and cohort-based analysis is to consider reproductive performance. A conventional method of evaluating reproductive performance is to consider the whole herd at a given point in time. For example, on a monthly interval, a DHIA herd summary may be generated that provides the herd's average days open, conception rate, heat detection rate, days to first service, etc. The difficulty with this approach is that these parameters represent different groups of animals in different stages of production. Average days open and conception rate are calculated for animals that are assumed to be pregnant, while heat detection rate and days to first service are calculated for animals that are eligible to be bred. Thus veterinarians are evaluating reproductive performance for two groups of different timeframes. In cohort-based analysis, we would evaluate these reproductive parameters for each cohort. For example, average days open, conception rate, and so on would be calculated for cows that had calved in the month of May. Any deficiencies identified would correspond to a specific timeframe and would be much more likely to indicate a potential management problem.

Survival Analysis

Survival analysis is a family of recently developed statistical techniques used to investigate the occurrence of events over time. Originally developed to look at mortality patterns in humans (hence the name "survival analysis"), all survival analysis techniques are based on the concept that the analyst is more interested in the length of time until an event occurs rather than the fact that the event occurs. For example, we know that eventually we will die; what is important is knowing when. Thus survival analysis can be used in any situation in which an initial status (e.g., alive) and a change in status (e.g., death) can be identified at some point later.

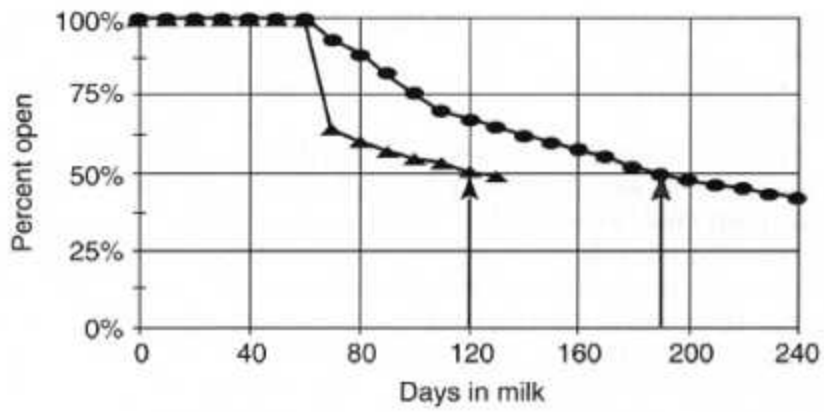

FIG. 3-19 Kaplan-Meier survival curve for days open for two reproductive management programs.

The ability to evaluate the length of time until an event occurs is well suited to livestock evaluation. There are numerous discrete events that may serve as initiating points in time, such as parturition, entry into a herd, diagnosis of a disease, and treatment with a product, to allow practitioners to evaluate the time interval until they change status by having a second event. Examples of intervals of interest are the intervals from parturition to conception, from disease diagnosis until removal, or from herd entry until disease diagnosis.

The main advantage of survival analysis over traditional methods of evaluation is the ability to evaluate data from animals that are "lost to follow-up." Loss of follow-up occurs when information regarding the timing of the second event in the interval of interest is not available. For example, if the veterinarian is interested in the length of time between calving and conception ("days open"), what value should he or she assign for a cow that is culled before being declared pregnant or for cows that have not been pregnancy examined yet? Conventional solutions to this problem are to exclude these cows from the average "days open" calculation or to assign some common value for cows leaving the herd. The approach used in survival analysis is to reason that even though the practitioner does not know when the second event occurred, he or she at least knows it did not occur before the point of the cow's being lost to follow-up. For example, the practitioner knows that the cow that was culled before being declared pregnant was open at least up to the point of the last breeding. Thus every cow eligible to be bred is included in the calculation, giving a more accurate (unbiased) and precise representation of what is happening in the herd.

The simplest type of survival analysis is the Kaplan-Meier survival curve. Fig. 3-19 shows actual Kaplan-Meier survival curves of calving to conception interval for a dairy herd before and after a new reproductive management program is adopted. Data required to generate this figure were calving date and conception date (if they existed) for each animal. Data then were summarized into calving to conception intervals, and the proportion remaining open at each 10-day interval was plotted.

Several advantages of survival analysis can be noted from Fig. 3-19. First, notice that the graph may be ended at any stage in time (e.g., 240 days in milk). For the period of time before the management change, 41.9% of animals had not been declared pregnant by 240 days in milk. This fact leads to the second advantage of survival analysis over calculating a simple average: it is not important whether animals open more than 240 days are lost to follow-up or had a long calving to conception interval (were an outlier). The survival curve is the same. When the average is calculated, especially

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in operations with small herd size, these animals pose a significant problem because an outlier may greatly influence the calculated average leading to a biased estimate of performance.

The arrows in Fig. 3-19 indicate the median days open (the point at which 50% of animals evaluated have become pregnant) for before and after the management change. This demonstrates a third advantage of survival analysis: the ability to calculate median values (or other proportions) directly from the figure. In this example, median days open has changed from approximately 190 days to approximately 120 days. Based on published (U.S.) costs associated with additional days open of $3.50 cow/day (Plaizier et al, 1997), the management change can be estimated as leading to a savings of $245/cow/lactation.

A fourth benefit of survival analysis, as shown by the current example, is that veterinarians can evaluate improvements in performance almost immediately. Notice that for the "after management change" group, data were only available up to 130 days in milk. With conventional methods, the veterinarian could not compare the "before" and "after" group until the "after" group had completed the lactation. However, with survival analysis, the veterinarian can see already that reproductive performance has improved, since the proportion of cows that are pregnant is higher (the proportion of cows open is lower) at any given day in milk. This leads to an important reproductive management concept that although reproductive performance is essentially equal (same slope) after 110 days in milk, improvements early in lactation have the largest effect on reproductive performance, since they reduce the pool of animals requiring additional breedings.

Use of Kaplan-Meier survival curves is a powerful tool that is being incorporated currently into livestock record systems. This technique has the advantages of the following:

- Using data from all animals so that more accurate and precise assessment of performance can be made
- Allowing calculation of various proportions, including median values, that can be made directly from the curve
- Allowing before-and-after comparisons to be made easily within a short timeframe
- Avoiding biased results, since the survival curves are less sensitive to outliers or lost to follow-up

Other more sophisticated analytic methods based on survival analysis concepts, such as Cox regression, exist; however, these methods are beyond the scope of this textbook.

Computer Models in Livestock Management

Why Develop Models? The use of computer models in livestock management is an extension of the record system. Models provide a means of asking the "what if" questions regarding contemplated management choices in the context of current herd performance. Therefore the principal reason for developing models is to assist in making decisions. Although there are many different potential applications for modeling, most models are used for one of three purposes. The first and most common purpose is to predict or compare the effects of manipulating system components. In this situation, veterinarians may want to predict the impact of a change on future performance of the system (termed "simulation") or may try to decide the best option from a list of possible changes (termed "optimization"). Simulation models can also be extended to allow comparison of the relative merit of a number of choices. The second purpose of models is to allow investigation of the interrelationship of complex systems, such as studying the economics of different reproductive management strategies for dairy herds using growth hormone. The latter purpose of models may not be clear at first. During the model building process, the modeler must define the system and how system components are believed to be related. Often in being forced to consider the model framework, the investigator identifies a piece of information that is poorly understood and has dramatic impact on the predicted outcome of the model. This is extremely useful in determining factors that need to be researched further and information that is vital to making an accurate decision.

Although models share many functions with experimental methods, there are several situations in which experiments cannot be performed and models are indicated. First, many systems, especially those that are biological, are extremely complex, and the interaction of the system components can influence greatly the behavior of the overall system (i.e., the outcome is greater than the sum of the parts). In this situation, experimental methods are not valid. Models that allow simultaneous consideration of all inputs must be used. Second, the enormity of manually evaluating all the possible combinations of factors is not feasible or economical in an experimental setting, so that modeling becomes the most practical option. Third, if the amount of time required to complete an experimental study exceeds the decision timeframe, models, which by nature compress the passage of time, are required. Finally, models allow the investigation of the effects of alternatives or situations that only potentially exist. This is extremely useful for evaluating the potential benefits of proposed interventions or the amount of money that would be logical to invest in developing a technology with a given effect.

Overview of Modeling Process. Fig. 3-20 shows the steps that are common to all types of models. This cyclical nature of modeling leads to an important concept: modeling is a dynamic process in that models are almost always refined with time.

Even though the model building process is basically the same for all models, several different model types exist based on function and approaches to handling variation. The first major classification scheme is based on the desired

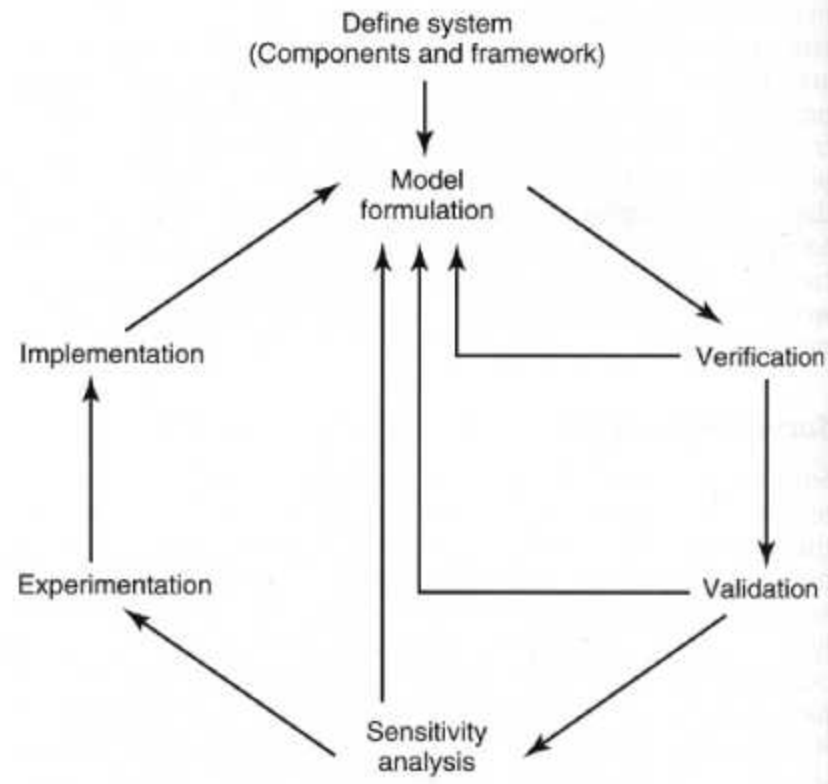

FIG. 3-20 Steps in model development. (Adapted from Martin SW, Meek AH, Willberg P: *Veterinary epidemiology*, Ames, Iowa, 1987, Iowa State University Press.)

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outcome of the model and is divided into optimization models and simulation models. As mentioned earlier, optimization models are models that determine the optimal or "best choice" solution for a given set of conditions. Examples of this kind of model would be linear programming used for ration balancing. Simulation models are sometimes called "what-if" models and determine the future effects of a given alternative. These models are most commonly run multiple times with different options to allow the comparison of several different strategies.

The second major classification scheme is the model's approach to handling biological variation. Basically two types of approaches may be used: a deterministic approach or a stochastic approach. Deterministic models are models in which no element of chance exists in the model calculations such that the results of the model are the same each time it is run. The outcomes in these models represent the "typical" or average response of the system and give no indication of the range of possible outcomes. Stochastic models contain elements of chance (usually the outcome is determined from a range of probabilities) in their calculations such that the result of the model given the same set of conditions are not the same each time it is run. Thus multiple runs are required to generate the range of responses. The major advantage of stochastic models is that the results provide both an estimate of the typical response and a distribution of possible responses compared with just an average response provided in deterministic models. The major disadvantage of stochastic models is the added complexity and requirement of multiple runs.

The final classification system relates to the way the model handles variations in model parameters and relationships over time. Models in which the values stay constant over the entire timeframe of the model are said to be "static," whereas models in which values are allowed to change over time are said to be "dynamic."

Difficulties of modeling. The greatest difficulty in modeling is dealing with the uncertainty inherent in the inputs (that is, the values used to describe the relationships of model components). There are three important concepts associated with uncertainty in every model: model assumptions, bias, and precision. The concept of model assumptions is relatively intuitive and represents the fact that in order for a model to be useful, it has to be simple. Bias is a measure of how accurate an estimate is compared with the truth. Precision is how reliable the estimate is. An analogy that may be useful for understanding the concepts of precision and accuracy is shown in Fig. 3-21. As indicated by this figure, the goal is to construct a model that hits the center of the target as often as possible (highly accurate and highly precise). If the model is inaccurate but precise, a consistent but wrong result occurs. If the model is imprecise but accurate, the right answer may appear most of the time but not be consistent. The worst-case scenario is the inaccurate, imprecise model that is both inconsistent and off-target.

The effects of assumptions, precision, and bias are best described by a description of the modeler's trade-off: as models become more complex, they become more accurate, but they also require more expensive data and become more difficult to interpret. In other words, the simplicity of a model decreases as the accuracy increases. Therefore the goal of model building can be described as creating the simplest model for a given amount of accuracy. How much accuracy is required is based on the relative costs of making an inaccurate decision.

The most common method to increase precision is to increase the sample size by collecting more data. By having more information, practitioners can become more confident that the model estimates are representative of the truth. Methods to decrease bias (or increase accuracy or validity) are more complex, since there are numerous potential sources of bias, each requiring different control measures. Sources of bias for statistical analysis and model building are generally classified into five categories: confounding bias, information bias, selection bias, follow-up bias, and specification bias. The most significant source of bias in model construction is specification bias. This class of bias occurs because when an analytic technique is chosen to determine the relationship between two model components, the assumptions inherent with that type of analysis are automatically acquired. These assumptions often make the difference between finding a significant effect or not.

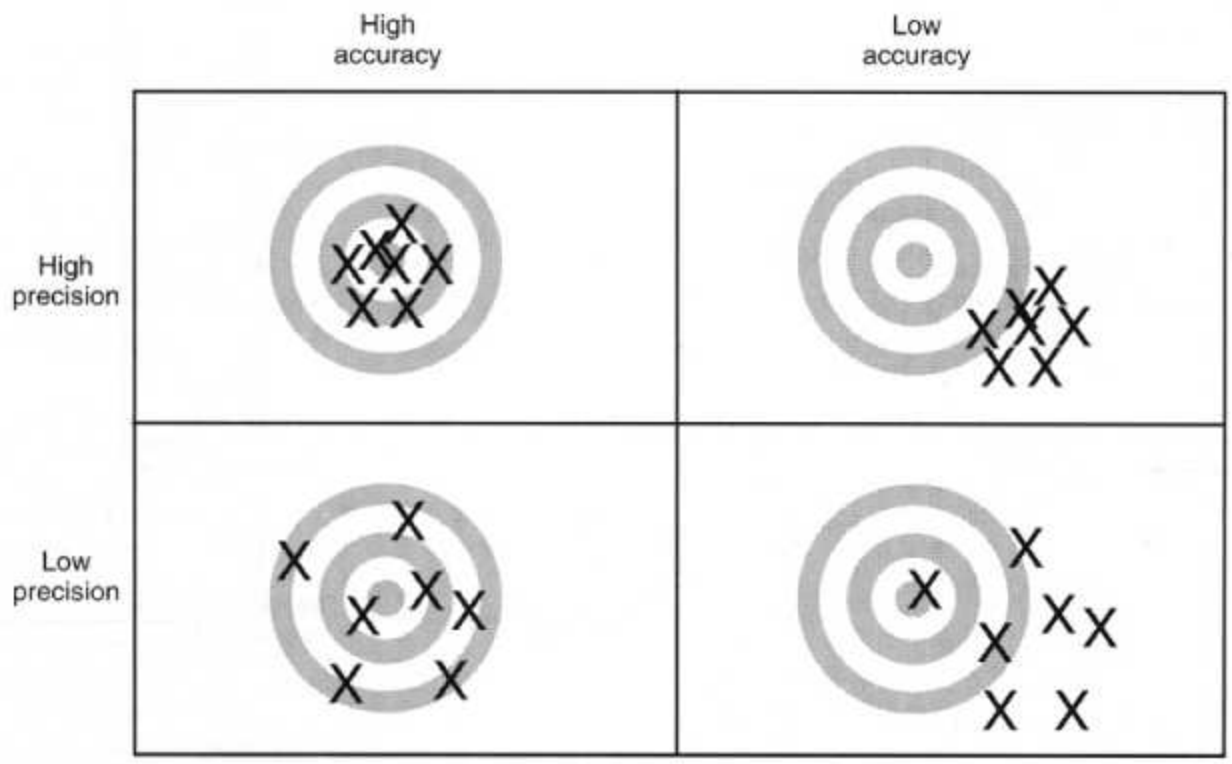

FIG. 3-21 Targets contrasting accuracy and precision.

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One of the most common questions regarding models is why model results differ, especially when the same data set is used as input in the analysis. These differences usually occur for three reasons: (1) models have different structural components or frameworks, (2) models may consider different input values or make different assumptions about inputs, and (3) models make different assumptions about the relationships of components.

Fig. 3-22 shows the schematic diagram for the DairyORACLE model developed at the University of Minnesota. DairyORACLE is a stochastic computer simulation model based on Monte Carlo methods designed for studying the impact of management interventions on dairy farms (Marsh, 1986; Kinsel, 1998). The Monte Carlo process is initiated by providing the model with a starting population of dairy cows of known characteristics. It is best to use the current performance measures of the herd in question. Users are then able to specify herd level performance, such as that shown in Fig. 3-23, and the occurrence and timing of subsequent events are determined by taking random observations from suitably defined probability distributions (Marsh, 1986). For example, a decision on whether a given animal becomes pregnant to a particular mating can be determined by taking random observations from the uniform distribution ranging from 0 to 1. If the user-defined conception rate is 40%, and the random number generated by the computer is greater than 0.40, the animal fails to conceive. If the random number is less than or equal to 0.40, the animal is deemed pregnant. The determination of the *timing* of a simulated event is more complex. The appropriate probability distribution selected for the timing of each event depends on the biological process being simulated (Marsh, 1986; Kinsel, 1998).

Fig. 3-24 shows a portion of the DairyORACLE projected herd performance summary from a 6-year run for a 176-cow dairy. User-defined inputs for this scenario were 60-day voluntary waiting period, 50% heat detection rate, 45% conception rate, 15% involuntary cull rate, 5% calf mortality rate, and a target milking herd size between 141 and 185 cows. Values listed in Fig. 3-24 indicate that for this scenario, excess heifer calves will be available to sell year 2 through 6 in the future, cull rates will range between 34.5% and 48.2%, and between 52 and 82 cows can be expected to be culled each year. Another example of a livestock decision model is DECI, developed for beef cattle by the Meat Animal Research Center in Clay Center, Nebraska.

Simulation models are decision aids that attempt to forecast future performance based on current performance and underlying conditions. They have different uses depending on the individual's perspective for using them. For the researcher, quality (complete and accurate) field data are difficult and expensive to obtain. Simulation models allow estimation of multiple effects and interactions of interventions from one data set that can be validated with field data. Therefore more research information can be obtained from a single data set. Research with financial models provides

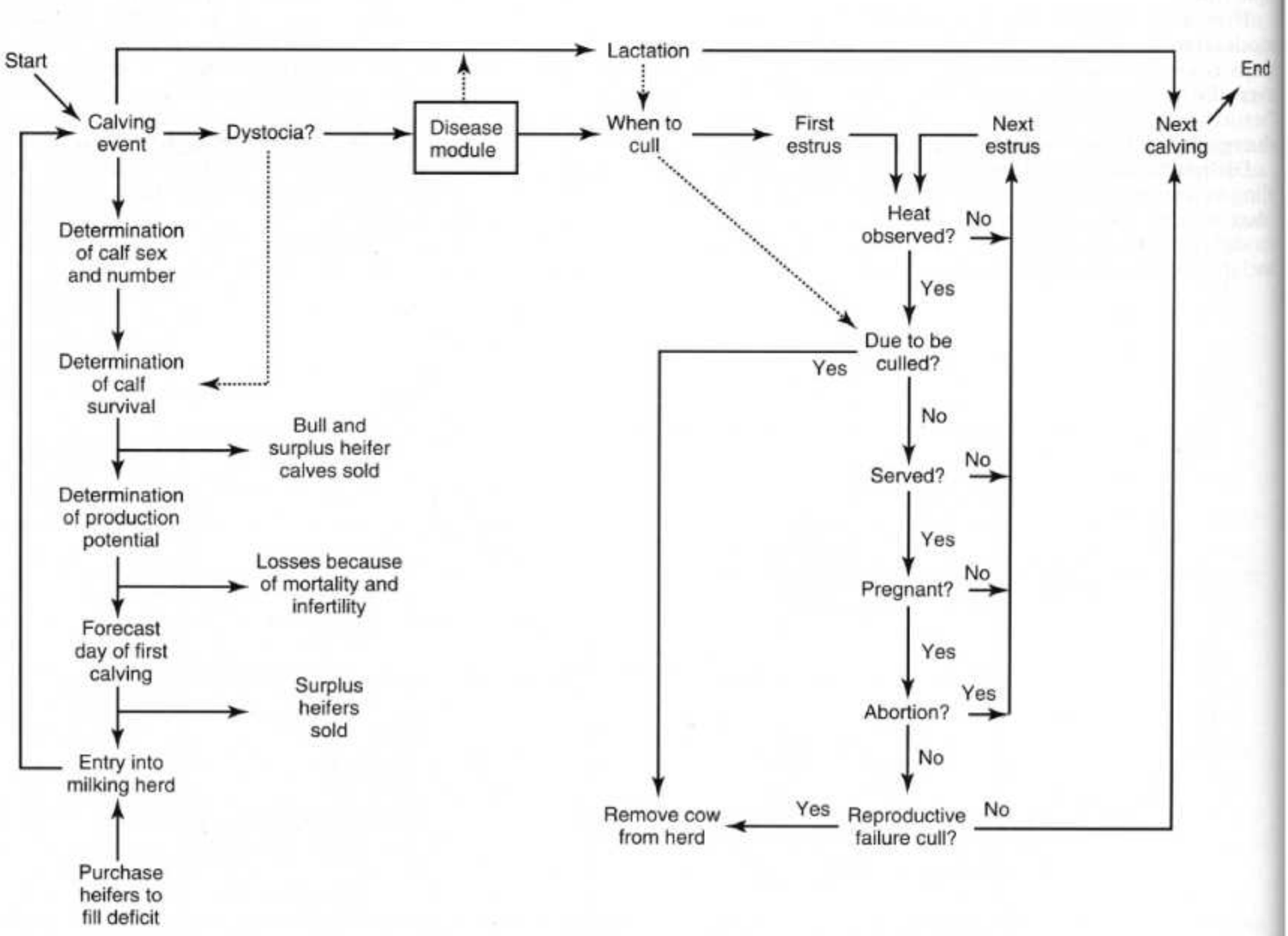

FIG. 3-22 Schematic diagram of three production cycles in DairyORACLE simulation model.

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Input Options

Accounting | Income Tax | Ration Makeup | Disease Incidence

Heifer Management | Herd Management | Culling Rules | Market Prices

Reproduction

Probability of a cow having a difficult calving (%)	5.0%
Proportion of calves born alive (%)	95.0%
DIM to begin serving all cows	50
DIM to cease serving a low to average producing cow	200
DIM to cease serving an above average producing cow	200
Probability of detecting a cow in heat (%)	50.0%
First service conception rate (%)	45.0%
Second or higher service conception rate (%)	45.0%
Probability of a cow aborting (%)	5.0%

Milk Production

Average 305 day M.E. milk yield for herd (1000 lbs)	18.0
Critical milk production for dry-off (lbs/cow/day)	35
Minimum desired length for the dry period (days)	56
Average body weight of cows in herd (lbs)	1400
Labor required per cow and replacement per year (hrs)	60.0

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FIG. 3-23 Herd management input screen from DairyORACLE simulation model software.

Close

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6
Median DIMFS	74	73	73	73	72	77
Mean DIMFS	80.42	81.34	84.58	83.01	82.13	79.39
Reservice rate	75.00%	68.81%	70.18%	66.19%	71.04%	68.51%
Median days open	107	126	110	111	121	108
Average days open	129.86	137.41	133.82	131.71	138.45	132.61
Reconception rate	74.48%	69.80%	71.56%	64.29%	70.49%	69.06%
Heat detection rate	49.38%	49.88%	47.16%	49.43%	49.21%	49.86%
First service conception rate	45.83%	41.01%	45.75%	46.04%	39.23%	43.55%
Service per conception rate	2.17	2.39	2.20	2.16	2.47	2.28
Service per conception ratio	2.20	2.40	2.19	2.24	2.60	2.35
Replacement rate	34.48%	41.42%	37.08%	48.17%	35.63%	37.74%
Calf mortality rate	6.32%	5.97%	6.37%	6.63%	4.71%	4.73%
Replacement herd size	156	147	126	117	118	111
Dairy herd size	174	169	178	164	160	159
Number of freshenings	176	223	208	223	182	182
Number of abortions	3	1	3	2	4	3
Number of calves born alive	190	201	204	196	170	169
Number of calves born dead	4	8	16	16	15	12
Number of raised calves kept	89	60	59	62	57	55
Number of springers purchased	0	0	0	0	0	0
Number of excess heifer calves sold	0	22	31	41	20	28
Number of cull cows sold	52	82	58	84	60	55
Number of springers sold	0	0	0	0	0	0

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FIG. 3-24 Sample DairyORACLE projected herd performance report for a 6-year simulation.

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clues to what information and interventions are associated with financial success and suggests what information is necessary for successful decision making.

From the producer's and consultant's standpoint, simulation models allow rapid comparison of alternative interventions within the context of herd dynamics based on the herd's own records. This comparison does more than just suggest a best course of action; it also provides two very important pieces of information. First, these models provide an estimate of the response (or range of responses for stochastic models) for a given intervention. For example, adding a total mixed ration might be estimated to boost milk production 4%. Thus a herd that currently produces 20,000 lb RHA will now produce 20,800 lb, and this increased production can be weighed against the cost of implementing the program. Second, simulation models provide a framework for planning for changes in feed requirements, facility requirements, labor needs, and so on that will be necessary to implement the intervention. Sophisticated models project cow flows, feed requirements, labor requirements, and cash flows over the timeframe of implementation.

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CHAPTER APPENDIX A*

CLIENT: _____ **Date:** _____ **Vet:** _____

REPLACEMENTS

☐ **Losses from excess heifer mortality**

Inventory: No. of heifers on farm: _____

No. of heifer deaths past year: _____ + _____ + _____ = _____

	Stillborn	Preweaning	Wean-Calve	Total no. of deaths
Goal	<1.5%	<5.5%	<2%	<9%

Population at risk: (_____ + _____ + _____) = _____
(Total dead) Heifers on farm No. dead/yr No. sold/yr

_____ = 0._____ − 0.09 = 0._____ × _____ × _____ = [ ]
(Population at risk) Death rate Goal Excess deaths Population at risk Avg. value Annual loss to excess deaths

☐ **Losses from overage heifers**

(_____ − 24 months) × 30 × _____ × _____ = [ ]
Avg age in month at first calving; days/mo; $/day; No. heifers/yr; Annual loss to overage calving

☐ **Losses from undersized Holstein heifers**

Size of recent 1st lactation cows: _____ Avg. heart girth _____ Avg. withers height

Heart girth (in)[1]	Body wt at calving (lb)	Differential from 1200 lb target wt, lbs milk first lact.
70	951-1000	−1079
71.5	1001-1050	−842
73	1051-1100	−583
74	1101-1150	−427
75.5	1151-1200	−211
77	1201-1250	0
78	1251-1300	41
79	1301-1350	172
80	1351-1400	212
81	1401-1450	222
>82	>1450	168

(_____ × _____) × _____ = [ ]
No. heifers entering herd/yr; Milk lost (lb); Milk price/lb; Annual production loss to undersized heifers

CULLING

Culling transaction: $_____ − $_____ = _____
Replacement heifer; Cull price; Avg. cost per cull

☐ _____ × (0._____ − 0.25) × _____ = [ ]
R# cows in herd; Annual turnover rate; Goal turnover rate; Avg. cull transaction; Annual cost of excess culling

*From Nordlund K: GOALFORM version 16, 1999, UW-SCM Dairy Production Medicine.

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CHAPTER APPENDIX A

UDDER HEALTH

☐ **Production losses due to subclinical mastitis**

Lactation group	No. head		Avg linear score (LS)	Goal		Production loss/unit LS		Milk lost per group
1st Lactation:	_____	×	(_____	− 2.0)	×	220 lb	=	_____
Other cows:	_____	×	(_____	− 2.5)	×	440 lb	=	_____

_____ × _____ = [ ]

Total lbs lost — Milk price per lb — Annual production loss to subclinical mastitis

☐ **Opportunity from milk quality premiums**

Maximum SCC premium from your milk plant: $0._____ per cwt (at 150,000 SCC)

Average quality premium received last year: $0._____ per cwt

Potential premium difference: $0._____ per cwt

_____ × _____ × _____ /100 = [ ]

Rolling herd avg — R# cows — Prem diff per cwt — Annual premium opportunity

☐ **Losses from acute mastitis**

_____ − _____ × $107 = [ ]

Estimated no. of mastitis cases/yr — Target no. of cases/yr (15% of R# cows) — Annual loss to clinical cases

The average mastitis flare-up will cost $107, as a combination of $12 in medication, $90 in discarded and decreased milk, $2 in veterinary costs, and $3 in labor.[2]

GENETICS

Average PTA$ of sires vs rolling herd average[3]

RHA:	<13,000	16,000	20,000	>23,000	Yours
Service sires	181	196	209	217	_____
First lact. cows	129	131	141	152	_____
Other cows	71	94	108	120	_____

☐ **Losses due to semen selection relative to top herds**

Lactation group	>23,000 PTA$		Yours		PTA$ diff.		No. identified head		
First lact. cows	152	−	(_____)	=	(_____)	×	(_____)	=	_____
Later lact. cows	120	−	(_____)	=	(_____)	×	(_____)	=	_____
								Total =	

[ ] Annual PTA$ losses

☐ **Losses due to herd bulls or unidentified sires**

Lactation group	Total No.		No. identified		No. not identified		Genetic loss[4]		
First lact. cows	(_____)	−	(_____)	=	(_____)	×	$134	=	_____
Later lact. cows	(_____)	−	(_____)	=	(_____)	×	$134	=	_____
								Total =	

[ ] Annual non-AI losses

Type traits statistically associated with longevity of dairy cows ranked in order of importance: udder depth, teat placement, fore udder attachment, and foot angle.

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CHAPTER APPENDIX A

REPRODUCTION (Average days in milk [lactating cows ONLY])

Reproduction problems result in cows having extended lactations. The herd average days in milk is reflective of long-term reproductive status of the herd.

Because average days in milk is highly variable in seasonally calving herds, the average days in milk should itself be averaged over the previous 12-month period.

1 _____
2 _____
3 _____
4 _____
5 _____
6 _____
7 _____
8 _____
9 _____
10 _____
11 _____
12 _____

Sum above and divide by 12 = _____ Rolling ADIM

☐ **Milk sales lost due to milking later and lower in lactation curve**

(_____ Rolling ADIM − 160 days) × _____ R# cows × 0.17 lb/day[5] × $_____/lb Milk price × 365 days × 0._____ % DIM = [ ] Annual production loss to long DIM

RDIM factors: Voluntary waiting period _____; heat detection rate _____; conception rate _____

☐ **Production loss due to long dry periods**

(_____ Avg days dry − 60 days) × _____ #2(+) lact. cows × $3.00/day* = [ ] Annual loss to long dry days

NUTRITION: ECONOMIC IMPACT OF PEAK MILK†

☐ Herd lactation avg (lb)	Peak, 1st lact.	Peak 2(+) lact.	Your 1st lact.	Your 2(+) lact.
27,000	87	116		
26,000	85	112		
25,000	82	109		
24,000	80	105		
23,000	77	102		
22,000	75	98		
21,000	72	94		
20,000	70	91		
19,000	67	87		
18,000	65	84		
17,000	65	84		
16,000	60	77		

_____ × _____ #1st Lact. × 333 lb/lact. × _____ Milk price/lb = _____

_____ Increase in peak goal (lb) × _____ #2(+) Lact. cows × 250 lb/lact. × _____ Milk price/lb = _____

☐ _____ Preliminary peak ($) − _____ Heifer size losses − _____ Genetic losses − _____ Mastitis LS losses = Preliminary peak milk ($) [ ] Annual $ from increased peaks

*Estimated value that could vary for every farm.
†Regression of Wisconsin DHIC 1998 data.

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CHAPTER APPENDIX A

Goal Form Summary of Herd

Date: _____

Item	Goal-form categories related to increased milk production	Categories related to cost control or price, but not production
Replacements		
Excess calf mortality		
Age at first calving		
Size at first calving		
Culling		
Excess cull rate		
Udder health		
Subclinical mastitis		
SCC Premiums		
Excess clinical cases	(80%)	(20%)
Genetics		
PTA$ relative to top herds		
PTA$ from unidentified sires		
Reproduction		
High rolling days-in-milk		
Excess days dry	(50%)	(50%)
Nutrition		
Peak milk opportunities		
Total		

Check:

_____ / _____ / _____ = _____

Production $ increase / Milk price per lb / No. of cows = Increase per cow per yr

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CHAPTER APPENDIX A

AREAS FOR ATTENTION

MANAGEMENT GOALS

1.

2.

3.

4.

PLANS/NEXT STEP

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CHAPTER 4

Control of Infectious Diseases of Food-Producing Animals

OTTO M. RADOSTITS

"Most human beings, indeed probably all living things, carry throughout life, a variety of microbial agents potentially pathogenic for them. Under most conditions, these pathogens do not manifest their presence by either symptoms or lesions; only when something happens which upsets the equilibrium between host and parasite does infection evolve into disease. In other words, infection in many cases is the normal state; it is only disease which is abnormal."

Rene Dubos: *Biochemical determinants of microbial diseases,* Cambridge, Mass, 1954, Harvard University Press.

This chapter describes the principles of the control of infectious diseases in herds or flocks of food-producing animals. Examples to illustrate the principles employed in the control and eradication of infectious disease in herds are used, where appropriate. The details necessary for the control of the specific infectious diseases of cattle, swine, sheep, and goats are available from other sources (Radostits et al, 2000).

INFECTIOUS DISEASES OF FOOD-PRODUCING ANIMALS

There are many infectious diseases of food-producing animals, caused by bacteria, viruses, protozoa, rickettsia, helminth parasites, and arthropod parasites (Box 4-1). The list provides the reader with an appreciation of the many different diseases that affect cattle, sheep, goats, and swine. Some of these diseases are important zoonoses.

MAGNITUDE OF THE PROBLEM

The control of the infectious diseases of food-producing animals must be considered in any health management program. These diseases are important for several different but related reasons, as follows.

Loss of Productivity and Economic Losses

Infectious diseases commonly cause loss of productivity, may cause considerable pain, and can result in major economic losses. Obvious examples include pinkeye in cattle, footrot in sheep, pneumonia in feedlot cattle, and foot-and-mouth disease in cattle. Parasitic gastroenteritis in sheep flocks, respiratory disease in beef feedlots, and mastitis in dairy cattle are examples of diseases that cause major economic loss in those individual animal industries.

Some diseases have been effectively controlled by vaccination or eliminated by eradication schemes. The clostridial diseases, for example, can be effectively controlled using vaccines. Brucellosis and tuberculosis have been eradicated from some countries, and progress toward their eradication in other countries is being made. However, control of tuberculosis in New Zealand has been hampered over the past two decades by the presence of an important wildlife reservoir, the Australian brushtail possum *(Trichosurus vulpelca)* (O'Neil and Pharo, 1995). In the United Kingdom the control of bovine tuberculosis is a major problem because of the reservoir of *Mycobacterium bovis* in badgers (White et al, 1993). Many infectious diseases, such as transmissible gastroenteritis of pigs, porcine respiratory and reproductive syndrome, and *Actinobacillus* pleuropneumonia of pigs, are still common, are difficult to control, and cause large economic losses. The bovine virus diarrhea virus (BVDV) causes acute clinical disease, but subclinical infections in dairy herds may be a major cause of economic loss because of decreased milk production and more severe respiratory disease in calves (Moerman et al, 1994). Following the development of improved diagnostic and research techniques, BVDV has now been shown to be associated with significant reproductive loss in cattle (McGowan and Kirkland, 1995). Surveys in Sweden have found that dairy herds with an increasing prevalence of bovine virus diarrhea virus antibody–positive cows (cows not vaccinated for BVDV) had higher frequencies of mastitis and retained placenta. Calving intervals were longer and the use of estrus-stimulating treatments was higher in herds with an increasing or high prevalence of BVDV antibody–positive cows (Niskanen et al, 1995).

In general, infectious diseases of the respiratory and digestive tracts and the mammary system, the body systems lined by mucous membranes and exposed to the environment, are endemic on most livestock farms and account for a large portion of the veterinary activity involved in disease control.

The direct costs associated with 30 different endemic diseases of farm animals in Great Britain were estimated (Bennett et al, 1999). The diseases included 13 diseases affecting cattle: bovine viral diarrhea/mucosal disease, enteric disease in calves, fascioliasis, infectious bovine rhinotracheitis, infectious bovine keratoconjunctivitis, lameness, leptospirosis, mastitis, lungworm, Johne's disease, pasteurellosis, salmonellosis, and summer mastitis in dry cows. Five diseases affected pigs: atrophic rhinitis, enteric disease in piglets, *Streptococcus suis* type II meningitis, swine dysentery, and swine influenza. Seven diseases affected sheep: acute enzootic pneumonia, blowfly strike, enzootic abortion, maedi visna, contagious pustular dermatitis (orf), sheep pulmonary adenomatosis, and toxoplasmosis.

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BOX 4-1

Infectious Diseases of Food-Producing Animals

DISEASES CAUSED BY BACTERIA
Mastitis
Neonatal streptococcal infection
Streptococcus suis infection of young pigs
Contagious bovine pyelonephritis
Cystitis and pyelonephritis of sows
Enzootic posthitis of ruminants
Caseous lymphadenitis of sheep and goats
Listeriosis
Erysipelas
Anthrax
Clostridial diseases
Colibacillosis of calves, piglets, lambs and kids
Escherichia coli infections in weaned pigs
Coliform gastroenteritis
Salmonellosis
Pasteurellosis
Brucellosis
Actinobacillus and *Haemophilus* pleuropneumonia of pigs
Tuberculosis
Johne's disease
Dermatophilosis
Necrobacillosis of the liver
Footrot of cattle
Digital dermatitis
Infectious foot rot of sheep
Footrot in pigs
Oral and laryngeal necrobacillosis
Porcine proliferative enteritis complex
Leptospirosis
Swine dysentery
Mycoplasmosis

DISEASES CAUSED BY VIRUSES, PROTOZOA, RICKETTSIAE, HELMINTHS, AND ARTHROPODS
Hog cholera
African swine fever
Postweaning multisystemic wasting syndrome of pigs
Enzootic bovine leukosis
Foot-and-mouth disease
Swine vesicular disease
Vesicular stomatitis
Vesicular exanthema of swine
Rinderpest
Malignant catarrhal fever
Bovine virus diarrhea
Transmissible gastroenteritis of swine
Viral diarrhea of calves, lambs, kids, piglets
Winter dysentery of cattle
Bluetongue
Porcine reproductive and respiratory syndrome
Swine influenza
Enzootic pneumonia of calves
Bovine respiratory syncytial virus pneumonia of cattle
Infectious bovine rhinotracheitis
Chronic enzootic pneumonia of sheep
Maedi of sheep
Jaagsiekte of sheep
Rabies
Pseudorabies
Caprine arthritis encephalitis of goats
Scrapie
Bovine spongiform encephalopathy
Border disease of sheep
Contagious ecthyma
Papillomatosis
Lumpy skin disease
Cowpox
Pseudocowpox
Bovine ulcerative mammillitis
Sheep-pox
Swinepox
Chlamydial abortion of ewes and cattle
Anaplasmosis
Eperythrozoonosis
Tick-borne fever
Heartwater or cowdriosis
"Q fever" of ruminants
Ringworm
Babesiosis
Coccidiosis
Sarcocystosis
Neosporosis
Cryptosporidiosis
Toxoplasmosis
East Coast fever
Tropical theileriosis
Trypanosomiasis
Diseases caused by helminth parasites
Diseases caused by arthropod parasites

The direct costs associated with a disease (C) are defined as the sum of the losses in expected output or resource wastage, or both, due to disease (L), the treatment costs incurred (T), and the costs associated with specific disease prevention (P) (that is, C = L + T + P). Details of the formula are available (Bennett et al, 1999). Simple spreadsheet models of each disease can be constructed, which can be used to estimate L, T, and P for the livestock population in Great Britain. These models can be used to estimate the direct costs associated with 30 different diseases in the country using a standardized approach and common valuation base that allows comparative assessments. The spreadsheet models and supporting documentation can be accessed from the following website: http://www.rdg.ac.uk/AcaDepts/ae/AEM/livestockdisea/.

Epidemics of Disease

Epidemics of infectious diseases in food-producing animals now represent a significant activity of veterinary practitioners and diagnostic laboratories. These epidemics may be associated with the intensification of livestock production, increased population density within herds, and a greater opportunity for the spread of infectious agents from infected to susceptible animals. Epidemics also may be due to the emergence of new strains of pathogens and to inadequate vaccination of cattle (e.g., the highly fatal form of bovine viral diarrhea that occurred in Ontario in 1993 to 1995 [Carman et al, 1998]). Epidemics of certain diseases may be difficult and expensive to diagnose, treat, and control and are a source of anxiety to the producer and the vet-

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erinarian. Even when a diagnosis can be made relatively easily, the clinical management of some diseases can be frustrating when affected animals do not respond to therapy and the mortality rate is high. Notable examples include outbreaks of peracute coliform mastitis in dairy cattle, *A. pleuropneumoniae* in swine, acute undifferentiated diarrhea of newborn calves, undifferentiated respiratory disease in feedlot cattle, and the porcine reproductive and respiratory syndrome. The difficulty of predicting the occurrence of disease also makes control uncertain.

Outbreaks of contagious animal diseases pose a major threat to livestock production. Outbreaks of diseases that are on List A of the Food and Agriculture Organization/Office International des Epizooties/World Health Organization (FAO/OIE/WHO) Animal Health Yearbook are especially feared because they are communicable diseases that have the potential for very serious and rapid spread, irrespective of national borders. (Diseases on List A include classic swine fever, African swine fever, foot-and-mouth disease, and swine vesicular disease.) These diseases are of serious socioeconomic or public health consequences and are of major importance in the international trade in livestock and livestock products (Horst et al, 1996).

In 1994 Belgium and Germany experienced serious outbreaks of classical swine fever (hog cholera). More than 7.4 million pigs were killed and destroyed, the total costs of which were estimated at almost 7.4 million ECU. However, these were only the direct costs (operational costs, market support, sanitary actions). Indirect costs, resulting from market disruption because of export restrictions, are often much higher and account for the major part of the total economic losses because of outbreaks of hog cholera and other List A diseases. Because of the great economic impact of outbreaks, adequate disease prevention and eradication are of major importance. Extensive research has been done on contagious animal diseases, but an integrated model that combines the various aspects of outbreaks and risks with economic consequences is still missing. An outline for an integrated modelling approach concerning risks and economic consequences has been proposed (Horst et al, 1996).

The recognition of bovine spongiform encephalopathy in England in 1985 and the subsequent public health concerns is an example of the enormous economic loss associated with a disease of cattle (Taylor, 1996). The disease is not of major economic significance to individual herds because of the low within-herd incidence. However, the national cost associated with detection and control procedures and the cost of compensation and disposal of affected animals and the loss of export markets was very high (Wells and Wilesmith, 1995). The occurrence of this disease has also resulted in a public questioning of the safety of cattle products as human food and a shift in the dietary habits of concerned people. This has caused a significant fall in beef consumption and beef prices. In response to market forces, Great Britain instituted a compulsory slaughter of at-risk but healthy cattle, with significant economic and social costs. The disease generated an extraordinarily, probably unprecedented, large number of field investigations of clinical cases, extensive diagnostic laboratory work, neuropathological research activities in human and veterinary medicine, drafting and implementation of legislation to control the disease, destruction of large numbers of cattle as part of the control procedures, and banning of beef exports from the United Kingdom. The eradication program combined with the decline in beef consumption had serious economic effects on both the dairy and beef cattle industries. The economic costs for eradication, including the destruction of animals over 30 months of age, and compensation to the farmers were estimated to be between $2 and $3 billion.

Diagnosis

The specific etiological diagnosis of subclinical infection is a major problem for the control and clinical management of some diseases such as Johne's disease, leptospirosis, enzootic pneumonia of swine, scrapie, and animals persistently infected with the bovine virus diarrhea virus. The routine laboratory diagnostic tests are time consuming, laborious, and often expensive. Being able to identify infected animals that are carriers and shedders is a prerequisite to the elimination and eradication of infection from a herd. Sampling the necessary proportion of animals in a herd for laboratory diagnostic testing and interpreting the results correctly are important related aspects of making an accurate diagnosis (Hancock et al, 1988). (See Chapter 5.)

Biotechnology is being used to develop new veterinary diagnostic tests that are based on such techniques as hybridization with nucleic acid probes, polymerase chain reaction (PCR), restriction fragment length polymorphism , and nucleic acid sequencing (Jackwood, 1994). The development of PCR has revolutionized the field of molecular biology (Rodriguez, 1997). The acid-based technique enables the rapid and sensitive detection of specific microorganisms. The technique consists of the enzymatic synthesis of millions of copies of target DNA sequence. Using a thermostable DNA polymerase, and a succession of cycles that includes denaturation of the template DNA and hybridization of specific DNA primers to the template and extension of the primers, practitioners can generate multiple copies of the target region enzymatically. Thus PCR provides a method for obtaining large quantities of specific DNA sequences from small amounts of DNA. The technique is widely used in veterinary research but has not yet found applications in routine microbiological analysis of veterinary clinical samples. PCR will most likely become the standard diagnostic test in situations in which the concentration of the suspected pathogen in the tissues is low, differentiation between morphologically identical organisms is required, or the immune response to the infection is uninformative. Diagnosis of viral diseases should be a major target for PCR application because laboratory tests for identification of viruses are slow, expensive, or insensitive. Among animal viral diseases, the following are good candidates for early development: foot-and-mouth disease, rinderpest, bluetongue, bovine herpesvirus-1, porcine reproductive and respiratory syndrome, swine influenza, pseudorabies, bovine leukemia, and BVDV. PCR can be used for the detection of those pathogens when in vitro cultivation is difficult, time consuming, or unavailable. The bacterial species for which PCR tests have been developed include *Staphylococcus aureus* strains that cause mastitis, *Listeria monocytogenes, Bacillus anthracis, Clostridium botulinum, Clostridium perfringens,* enterotoxigenic *Escherichia coli, Salmonella* spp., *Yersinia enterocolitica, Helicobacter pylori, Brucella* spp., *M. bovis, Mycobacterium paratuberculosis, Dichelobacter nodosus, Leptospira* spp., *Borrelia burgdorferi, Mycoplasma mycoides* spp. *mycoides, Mycoplasma hyopneumoniae, Chlamydia psittaci,* and *Coxiella burnetii* (Rodriguez, 1997).

Principles of Control

Educating livestock producers about the importance of the various risk factors associated with infectious diseases and the strategies for control is a challenging responsibility for the veterinarian (Williamson et al, 1988). Many infectious diseases could be controlled effectively and economically if livestock producers adopted the management procedures that are effective and readily available. Producers adopt certain control procedures more readily if they understand

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the reasons for the procedure. For example, many dairy producers do not fully understand the principles of mastitis control. Thus the *elimination of existing infections* and the *prevention of new infections* do not occur because dry cow therapy and postmilking teat dipping are not implemented to apply those principles. When dairy producers do appreciate those principles, the adoption rate of the control procedures increases significantly.

The control of some infectious diseases of food-producing animals can be unreliable because of the questionable efficacy of the vaccines available. Most vaccines are evaluated in animals that are vaccinated and then challenged with the infectious agent(s) under experimental conditions. Until recently, most vaccines were not evaluated in well-designed field trials against naturally occurring disease under commercial farm conditions with emphasis on cost effectiveness. This is discussed in general terms later in this chapter and more specifically in other chapters that discuss particular vaccines.

Use of Antimicrobials in Food Producing Animal Production

In modern food-producing animal production, animals are kept in groups of varying sizes so that the individuals share a common air and ground space, in close contact with one another and exposed to feces and urine, allowing the spread of microbial agents to occur easily. Antimicrobial agents are used in food animals for therapy and prophylaxis of bacterial infections and in feed to promote growth. The use of antimicrobials in food animals may cause problems in the therapy of infections by selecting in resistance among bacterial pathogens in animals that then may be transferred to humans (Aarestrup, 1999). Because of the public health concerns regarding the use of antimicrobials in food animals, the following is a brief summary of the salient features of the subject.

Under intensive systems of food animal production, it is rational to provide medication when necessary to the entire group whether the size is 20 or 20,000 because the source and occurrence of infection would be the same. In fact, the use of subtherapeutic levels of antimicrobials is one of the methods of health and production management that has allowed confinement housing and large numbers of animals to be maintained in production facilities of a given size. This has contributed significantly to the lower costs of production and ultimately to the lower cost to the consumer for meat, milk, and eggs.

About 40% of the antimicrobials produced in the United States are used in animal feed, but exact figures are unavailable. This represents 55% to 60% of the total production of penicillin G and tetracyclines, with 50% of the total animal feed medication being tetracyclines. In the United States this may represent up to 8500 tons, a large amount in terms of the microgram antibacterial potency of these chemicals (Table 4-1). However, on an individual animal basis, the amounts are small. Moreover, contrary to popular misconception, agricultural use of antimicrobials is extensively regulated. Under the food and drug legislation in both Canada and the United States, there are three uses of antimicrobials in agriculture: as *feed antimicrobials*, as *over-the-counter (OTC) drugs*, and as *veterinary prescription drugs* (Prescott, 1997).

The amounts of antibiotics used in livestock production in the United States are summarized in Table 4-1, and the amounts of antimicrobial agents prescribed to people in Canada in 1996 are shown in Table 4-2 (Prescott, 1997).

Antimicrobials Used in Beef Cattle Health Management and Production

Antimicrobials are used in beef cattle health management and production in North America for the treatment of clinical disease in cattle of any age, for prophylaxis of certain diseases, and for growth promotion of young growing animals, usually feedlot animals. The successive stages of the production life cycle in cattle include the nursing calf from birth to weaning at 6 to 8 months of age, the weaned beef calf, the growing yearling on pasture, the feedlot animal fed high-energy rations for 6 to 12 months, breeding females, and bulls of various ages.

Treatment. The therapeutic use of antimicrobials occurs after a diagnosis of a disease is made and treatment is governed by label instruction.

Cattle of all ages from the young calf to the mature cow may require treatment with antimicrobials for clinical disease caused by bacteria. The most common diseases are caused by bacterial infections of the respiratory and alimentary tracts, the mammary gland, and the reproductive tract.

Oxytetracycline, florfenicol, tilmicosin, and trimethoprim-sulfonamides are used parenterally for the treatment of acute undifferentiated respiratory tract disease of feedlot cattle (Harland et al, 1991; Guichon et al, 1993; Hoar et al, 1998). It is noteworthy that, in spite of the intensive use of the com-

TABLE 4-1

Estimated Annual Antibiotic Use in Livestock in the United States, 1985 (thousands of kg)

Species	Therapeutic	Subtherapeutic	Growth Promotion
Cattle*	458	1100	340
Swine	250	3578	1391
Poultry†	304	580	315

*Mostly beef cattle.
†Mostly meat chickens.

TABLE 4-2

Antimicrobial Agents Prescribed for Humans in Canada, 1996

Antimicrobial	No. of Prescriptions (millions)
Amoxicillin	6.78
Cephalosporin	3.31
Erythromycin	2.72
Trimethoprim-sulfonamide	1.76
Quinolones	1.66
Extended-spectrum macrolide	1.48
Other broad-spectrum penicillin	0.95
Antifungals	0.93
Tetracyclines	0.89

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mon antimicrobials for more than 30 years, *Mannheimia haemolytica (Pasteurella haemolytica)*, a primary cause of fibrinous pneumonia in cattle, has not developed significant antimicrobial resistance.

Medication of High Risk Groups of Individual Animals (Metaphylaxis) for Respiratory Disease. Feedlot animals at high risk of acute undifferentiated bovine respiratory disease, most of which is bacterial pneumonia, are administered antimicrobials at therapeutic doses on arrival at the feedlot to reduce morbidity and mortality (Harland et al, 1991). Long-acting oxytetracycline (20 mg/kg BW) and tilmicosin (10 mg/kg BW) are the parenteral antimicrobials currently used (Morck et al, 1993). It is estimated that 10% to 20% of feedlot animals receive prophylactic-metaphylactic tilmicosin and 20% to 40% of feedlot animals receive prophylactic-metaphylactic long-acting oxytetracycline. When oxytetracycline is used, it is sometimes used with a "follow-up" injection 3 days later.

Florfenicol is also used for the treatment of acute bovine respiratory disease and is considered superior to tilmicosin when feedlot calves have previously received tilmicosin prophylaxis on arrival (Jim et al, 1999).

Subtherapeutic Medication of Feed. The subtherapeutic dose of an antimicrobial is defined in the United States as the use of the drug at less than 200 g per ton of feed. Antimicrobials used at these levels are intended to control certain infectious diseases and are provided most commonly in the feed and occasionally in the water supply. Some of the common disease complexes controlled with subtherapeutic medication of the feed of feedlot cattle are outlined here.

Respiratory Disease (shipping fever pneumonia). It is common practice to feed chlortetracycline (350 mg/head/day) and sulfamethazine (350 mg/head/day) (Aureo S-700 G) to high-risk feedlot animals during the first part of the feeding period (typically 50 to 60 days) because of significant reductions in the *Haemophilus somnus* disease complex–associated mortality under commercial field trial conditions. Aureo S-700 G is licensed for the first 4 weeks of the feeding period "as an aid in the maintenance of weight gains and feed efficiency in cattle during periods of stress, due to weaning, shipping or handling" (Gallo and Berg, 1995). It is estimated that 20% to 30% of feedlot animals receive this type of program.

The inclusion of a feed additive containing 350 mg chlortetracyline and 350 mg sulfamethazine each per head per day in the feed of feedlot cattle from arrival in the feedlot to day 56 of the feeding period significantly improved average daily gain and reduced the incidence rate of respiratory disease, the rate of relapses, and the rate of chronic respiratory disease (Gallo and Berg, 1995). Performance and health improvements from using the feed additive were cost effective.

Coccidiosis. Decoquinate in the feed is occasionally used to prevent coccidiosis in feedlot cattle.

Foot Rot. Oxytetracycline or chlortetracycline in the feed is occasionally used to provide mass medication to control outbreaks of footrot (1 g/head/day).

Liver Abscesses. Liver abscesses in beef cattle are the result of high-level grain-feeding programs (Nagaraja and Chengappa, 1998). The incidence, averaging from 12% to 32% in most feedlots, is influenced by several dietary and management factors. Liver abscesses represent a major economic liability to producers, packers, and ultimately consumers. Economic losses are due to reduced feed intake, reduced weight gain, decreased feed efficiency, and decreased carcass yield. *Fusobacterium necrophorum*, a member of the ruminal anaerobic bacterial flora, is the primary etiological agent. Ruminal lesions resulting from acidosis are generally accepted as the predisposing lesions for liver abscesses. Certain virulence factors of the organism permit its penetration and colonization of the ruminal wall and subsequent entry and establishment of infection in the liver. Control of liver abscesses in feedlot cattle on high-level grain feeding has depended on the use of antimicrobials. Five antimicrobials—bacitracin methylene disalicylate, chlortetracycline, oxytetracycline, tylosin, and virginiamycin—are approved for prevention of liver abscesses in feedlot cattle. Tylosin is the most effective and the most commonly used feed additive and reduces liver abscesses by 40% to 70%.

Virtually all feedlot animals receive antimicrobials to reduce the incidence of liver abscesses. In most situations they are fed for the entire feeding period. However, if they are used to control bovine respiratory disease or undifferentiated fever or the *H. somnus* disease complex for a portion of the feeding period, then the antimicrobial for liver abscess reduction is often excluded from the ration. It should be noted that although a reduction in the incidence of liver abscesses is the licensed claim for these products, the inclusion of these products results in significant improvements in average daily gain or feed efficiency. It is currently not known whether or not the observed improvements in average daily gain or feed efficiency are a direct result of antimicrobial usage, an indirect result of the reduced incidence of liver abscesses, or a combination of both. The antimicrobials used include tylosin, oxytetracycline, and chlortetracycline. Of these antimicrobials, tylosin is the only compound licensed to reduce the incidence of liver abscesses. However, a series of commercial feedlot studies have demonstrated that both oxytetracycline and chlortetracycline are effective at reducing the incidence of liver abscesses, and both are licensed in the United States for this claim. Oxytetracycline and chlortetracycline are also licensed to improve average daily gain and feed efficiency in the United States. In Canada, tylosin (11 ppm) is the most commonly used antimicrobial to reduce the incidence of liver abscesses (estimate is 40% to 60% of feedlot animals) and tylosin is cocleared with monensin at 33 ppm. Oxytetracycline (11 ppm) is the next most commonly used antimicrobial to reduce the incidence of liver abscesses (estimate is 30% to 50% of feedlot animals). Chlortetracycline (11 ppm or 350 mg/head/day) is used occasionally to reduce the incidence of liver abscesses (our estimate is less than 5% of feedlot animals). Both oxytetracycline and chlortetracycline require veterinary prescription in Canada for this use and the combination with monensin.

Growth Promotant Antimicrobials in the Feed. Various antimicrobials used as feed additives and hormonal implants are approved in North America for use throughout the feeding period of feedlot cattle to enhance growth rate and feed efficiency. Antimicrobial feed supplements for growth promotion have been used extensively in almost every major livestock-producing country for the past 40 years. It is generally accepted that their use has contributed to lower animal production costs and ultimately to lower costs to the consumer for meat, milk, and eggs.

The antimicrobials used as growth promoters are grouped broadly into *ionophores* and *nonionophores*. Ionophores are compounds that beneficially modify ruminal fermentation activity. Monensin, lasalocid, laidlomycin, and salinomycin are the most commonly used. Monensin was the first ionophore approved in 1976 for increasing feed efficiency in feedlot cattle and in 1978 was approved for increasing rate of gain of pasture cattle. It was also shown later that monensin is effective in preventing coccidiosis. Generally, in grain-fed animals, ionophores depress feed intake, but body weight gain is increased or

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unaffected and feed efficiency (feed-gain) is improved. In pasture-fed cattle, ionophores do not reduce feed intake but body weight gain is increased, thus resulting in improved feed efficiency.

The effectiveness of ionophores in achieving increased efficiency of feed conversion and, under some conditions, in improving the rate of gain is attributed to alterations in ruminal fermentation. Ionophores are not used in human medicine and do not pose a risk to human health from the development of antimicrobial resistance in animal pathogens that may be transferred to humans.

All feedlot animals receive ionophores for the entire feeding period to control coccidiosis and to improve feed efficiency. The Canadian options include monensin, lasalocid, and salinomycin; however, the overwhelming majority (an estimate is 95% plus [Radostits, 1999]) of feedlot animals receive monensin. Monensin is generally fed at levels from 22 ppm to 33 ppm, with several postlicensing studies conducted under commercial feedlot conditions demonstrating that 25 ppm is significantly more cost effective than 33 ppm. However, including monensin at 25 ppm requires a veterinary prescription, since the product is licensed at 33 ppm for the entire feeding period or 11 ppm for 28 days followed by 33 ppm for the remainder of the feeding period to improve feed efficiency and at 22 ppm for the prevention of coccidiosis.

Nonionophore antimicrobials are the conventional antimicrobials used as feed supplements and include avoparcin, bacitracins, chlortetracycline, sulfonamides, flavomycin (bambermycin), neomycin, oxytetracycline, spiramycin, tylosin, and virginiamycin. These antimicrobials are a diverse group that differ in chemistry, primary antibacterial spectrum, mode of action of bacterial inhibition, molecular weight, and ability to be absorbed from the intestine. Those that are not absorbed from the intestine or poorly absorbed at the low dosage used are more acceptable as feed additives because of the absence of residues in milk and meat and because there is no need for a withdrawal period before slaughter.

Antimicrobials used in the feed decrease the amount of feed needed, increase the rate of weight gain, and improve feed efficiency. The growth promotion response in cattle is much more varied than in swine or poultry depending on the level of subclinical infection, level of management and nutrition, and environmental and managemental stressors such as recent shipping and mixing feedlot animals from many sources. Antimicrobials are used as feed additives for growth promotion in growing cattle at continuous low levels (2 to 50 g/ton of feed). Most studies indicate that chlortetracycline, oxytetracycline, and zinc bacitracin are the most effective nonionophore antimicrobials for improving the performance of beef cattle.

Chlortetracycline is used at 11 mg/kg of complete feed as an aid in stimulating growth rate and improving feed efficiency in calves. Oxytetracycline hydrochloride is used at 11 mg/kg of complete feed for growth promotion in calves.

The mechanism of action of antimicrobials in improving growth and enhancing feed efficiency is not fully understood. The most commonly accepted explanation is that the growth response is primarily due to actions on the microbial flora of the intestine. This is supported by the observation of a lack of improved growth under germ-free conditions. At least four general modes of action have been postulated to account for growth promotion by antimicrobials:

- Metabolic effect by directly influencing the rate or pattern of metabolic processes
- Nutrient sparing effect by altering the bacterial populations and conservation of nutrients
- Control of subclinical disease by suppressing bacteria causing clinical or subclinical infections
- Modification of ruminal fermentation by altering rumen population to improve fermentation efficiency

Most feed additive antimicrobials have their antibacterial activity against Gram-positive bacteria, but some Gram-negative bacteria are also susceptible. The tetracyclines are inhibitory to both Gram-positive and Gram-negative bacteria. It is important to note that antimicrobials have a beneficial effect on growth rate other than through their effect on enteric microflora.

Antimicrobial Use in Swine Herds

Antimicrobials are used extensively in newly weaned pigs, a critical time for infections in young animals, and to a lesser extent in growing and finishing pigs where their use may not be effective (Prescott, 1997). Raising pigs under intensified conditions has similarities to beef feedlots where large numbers of animals are fed under intensified conditions.

A 1991 mail survey of swine herds in Ontario, Canada, found that 86% of herds added antimicrobials to starter (weanling pig) rations, and only 29% added these drugs to finishing pig rations (Dunlop et al, 1998a). The most commonly used antimicrobials were tylosin, carbadox, and furazolidone in weanling pigs and tylosin, lincomycin, and tetracycline in finishing pig rations. Water medication of grower-finisher pigs was practiced on 25% of farms; 80% of farms had injected at least some grower-finisher pigs with antimicrobials in the 12 months preceding the survey. Approximately 20% of the producers added antimicrobials to finisher rations for growth promotion purposes only, while others used them for the treatment of disease, prevention, control, or a combination of both. Among those not using antimicrobials in finisher rations, 83% did not consider them necessary, and 37% were concerned about the potential for residues in marketed pigs.

Feed additive antimicrobials are those that livestock producers can order without a veterinary prescription through licensed feed mills for growth promotion (2 to 50 g/ton), for subtherapeutic use (200 g or less/ton of feed), or for disease treatment (over 200 g/ton of feed). Subtherapeutic use, the most contentious and the largest of the uses, encompasses prevention of specified diseases but includes growth promotion in the face of certain diseases. Most feed antimicrobials are used for this purpose, particularly in swine. Many of the feed antimicrobials are unique to agriculture (carbadox, flavomycin, monensin, salinomycin, virginiamycin). Other feed antimicrobials in common use in animals (bacitracin, lincomycin, sulfonamides, tetracyclines, tylosin) are not commonly used in human medicine. Only penicillin G, which is often used in swine feed in combination with sulfonamides and tetracyclines, is commonly used in human medicine.

Potential Drug Residues in Meat and Milk

In food-producing animal health management and production, antimicrobials are used for the treatment and prevention of infectious diseases and to enhance growth promotion. These uses of antimicrobials represent one of several important health management strategies that contribute to animal health and well being and to the economical production of wholesome meat and milk products. The control of animal disease also means control of certain infectious diseases that may be transmitted to humans. However, there are some potential human health hazards associated with antimicrobials used in food animals. Residues of drugs may occur in meat and milk and could enter the human food

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chain and increase the risk of ill health in persons who consume products from treated animals. Of greater current importance is the potential for the emergence of antimicrobial resistant enteric bacteria that could be transferred to humans, resulting in clinical disease that may be difficult to treat.

The use of antimicrobials for the treatment of infectious diseases in food-producing animals may result in drug residues in meat and milk if the withdrawal periods following use of the drugs are not observed. There is now much public health concern about residues in meat and milk. The human consumption of meat containing more than the tolerable levels of residues of antimicrobials could cause hypersensitivity reactions if the person is already sensitive to that particular antimicrobial because of previous exposure, usually through medication. Remarkably, however, since the introduction of antimicrobials some 40 years ago, on a worldwide basis there have been only a few reports of suspected cases of hypersensitivity reactions because of residues in meat. Direct human toxicity caused by the ingestion of meat containing more than the tolerable levels is unlikely because the levels are so low.

Quality assurance through residue screening has become an important health management activity for producers and veterinarians. Using the highly sensitive laboratory techniques now available, smaller and smaller amounts of residues can be detected. Consideration now must be given to tolerance levels that do not constitute a human health hazard. However, satisfying the consumer of the safety of tolerance levels is a major educational exercise. Residues are being found in cull dairy cows, veal calves, and market pigs, and the most frequently cited cause is failure to observe the withholding time for the drug. Several different antimicrobial agents, including neomycin, streptomycin, sulfamethazine, tetracycline, and gentamicin, were found in the tissues of bob veal calf tissues surveyed by the U.S. Department of Agriculture (USDA) Food Safety Inspection Service during the fiscal year 1988 (Wilson et al, 1991a,b,c).

The livestock producer is considered to be the person responsible in over 80% of the cases for which responsibility was determined. Poor production practices, associated primarily with inadequate medication records, contribute to the incidence of drug residues. The Milk and Dairy Beef Quality Assurance Program (MDBQAP), a 10-point Hazard Analysis Critical Control Points (HACCP) program, was intended to promote rational protocols directed at managing and reducing the use of antibiotics on the farm (Sischo et al, 1997). Certification in the program is not associated significantly with a reduced risk of having violative antibiotic residues in milk (Gibbons-Burgener et al, 1999). An on-farm risk assessment was done using the cooperation of dairy field representatives and 250 dairy producers to determine the risk for antibiotic residue violation. A lack of adequate treatment records was the highest risk factor for antibiotic residues, followed by deficiencies in understanding how to use antibiotics, and poor relationships between veterinarians and their clients (Sischo et al, 1997). When field representatives jointly used an interactive risk assessment tool with their producers, most producers responded by decreasing risk by approximately 19%. More farms kept written records or kept more complete records than previously. Thus field representatives were effective in their role as educators and as agents of change, promoting a reduction in the risk for antibiotic residues.

Although harmful residues are extremely rare, the problem is perceived by the public as a potential human health hazard. One newspaper report indicated that antimicrobial residues were found in 38% of milk samples tested from milk purchased off the shelf in Washington, DC. No documented, published evidence has been found of any adverse reaction in humans directly attributable to the presence of antimicrobial residues in meat.

Whether the drug to which the animals are exposed reaches the consumer depends on a number of factors, including the specific drug involved, its absorbability and pharmacokinetics, the interval from administration of the last dose of the drug until slaughtering, the tissue to be eaten, and the degree of cooking of the meat.

Antimicrobial residues in meat above the maximal tolerable levels occur extremely rarely and are usually the result of the slaughter of cattle that were treated therapeutically and not retained on the farm until expiry of the withdrawal period for the drug in question. The percentage of drug residue violations in beef in North America is extremely low and continues to decrease as producers become more knowledgeable about the judicious use of antimicrobials and their withdrawal period. *Feedlot owners want to produce wholesome meat free of harmful residues of any kind.* Statistically valid random sampling and testing of beef carcasses are done routinely in federally inspected abattoirs across Canada. In addition, carcasses with evidence of drug injection sites are tested as suspect and condemned if positive for antimicrobials. A follow-up investigation is conducted, and future shipments from the farm are examined specifically for violations.

There is no evidence that the subtherapeutic or prophylactic use of antimicrobials in the feed of beef cattle has resulted in residues in the tissues of treated animals. In large part this is due to the low levels of drug that are achieved in the tissues compared with the higher levels following therapeutic use of the drug. Adherence to the stated withdrawal periods allows for the elimination of the drug, and there is no public health hazard (National Research Council, 1999). In a 1991 to 1993 study performed by the Food Safety Inspection Service Residue Violation Information System of violative chemical residues in U.S. beef, most of the animals found to have violative residues were bob calves and culled cows. In bob calves neomycin was the most frequently identified violative chemical, followed by tetracycline, gentamicin, oxytetracycline, and penicillin. In culled cows penicillin was the most frequently identified violative chemical and was most frequently found in combination with other chemicals in cows with multiple violative residues (Gibbons et al, 1996). In a 1-year survey of beef cow-calf herds in Tennessee, the drugs most commonly used were anthelmintics and insecticides for the control of external and intestinal parasites (Kelch and New, 1993). Antimicrobials were seldom used for prophylaxis.

In summary, there is no evidence that the judicious therapeutic, prophylactic, or subtherapeutic use of antimicrobials in beef feedlot animals, the use of which includes strict adherence to the withdrawal times, constitutes a human health hazard associated with drug residues in tissues.

Antimicrobial Resistance

There is concern that the use of subtherapeutic levels of antimicrobials in the feed of farm animals can result in the development of antimicrobial-resistant enteric bacteria that are then transferred to humans, where they may cause disease that is consequently difficult to treat. The genetic material coding for antibiotic resistance is known as the R factor; this is usually carried on plasmids and can be transferred among strains of the same species of bacteria and also among different species. The major means whereby humans can be infected with organisms harboring these R factors is through meat and meat products, which are often contaminated with antibiotic-resistant enteric bacteria. R factors can be transferred to humans by direct transmission to their intestine,

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where it may colonize. However, most animal strains colonize only for short periods. The organism may also transfer the R factor to resident strains in the human intestine but not colonize. A third mechanism is indirect; the organism, after leaving the host animal, may transfer R factors to other organisms, such as another strain of *E. coli* 0157:H7 or *Salmonella* sp., which subsequently may colonize the human intestine. The possibility that this could occur on the surface of meat was examined, but it did not occur. However, the results of large-scale surveys in Europe and North America have indicated that the use of antibiotics in livestock farming during the past 20 years has not compromised public health.

When the prevalence of resistance in specific bacteria increased, the increase was usually associated with the introduction of a new antimicrobial drug in human or veterinary practice. A literature review indicated that there is no evidence that the subtherapeutic use of antimicrobials in livestock feeds is a human health hazard (Institute of Medicine, 1989). Although the biological possibility exists, neither drug residues nor the presence of bacteria resistant to antimicrobials has been documented as a problem.

Since 1993 a multiple antibiotic resistant strain of *Salmonella typhimurium* DT 104 has accounted for most cases of salmonellosis in cattle in the United Kingdom (Evans and Davies, 1996; Threlfall et al, 1998; Wall et al, 1995), the United States, (Besser et al, 1997), Australia (Mackie et al, 1996), and Canada (Poppe et al, 1998). Originally isolated in England in 1984 from a human specimen, *S. typhimurium* DT 104 remained rare until about 1990 when there was a rapid increase in isolation rates in humans and the first isolation in livestock. Cattle are thought to be the main reservoir of infection (Calvert et al, 1998). The herd-associated risk factors for disease caused by multiple-resistant *S. typhimurium* DT 104 in cattle herds in Great Britain have been examined (Evans, 1996). The epidemic strain is classified as R-type ACSSuT through being resistant to ampicillin, chloramphenicol, streptomycin, sulfonamides, and tetracycline. Some strains of *S. typhimurium* DT 104 have chromosomally integrated multiple drug resistance (Threlfall et al, 1994). Since 1994, the percentage of DT 104 with additional resistance to trimethoprim and reduced sensitivity to ciprofloxacin has increased. The emergence and dissemination of multiresistant DT 104 with reduced sensitivity to ciprofloxacin (a fluoroquinolone) have occurred since the licensing for veterinary use in the United Kingdom in 1993 of the related fluoroquinolone, enrofloxacin, which has subsequently been used for treatment and prophylaxis in both cattle and poultry in the United Kingdom (Frost et al, 1996; Threlfall et al, 1998). In contrast to the United Kingdom, while multiresistant strains of DT 104 have been isolated in the United States, none of the human or veterinary isolates of DT 104 have been resistant to fluoroquinolones (Besser et al, 1997; Glynn et al, 1998). Since chromosomal integration has been cited as a method whereby bacterial cells can retain antimicrobial resistance genes in the absence of selective pressure, it is unlikely that withdrawal of antimicrobials would have any significant effect on the current epidemic of DT 104 ACSSuT in cattle in Britain (Threlfall et al, 1994).

Nalidixic acid is a first generation quinolone antimicrobial now used to detect changes in susceptibility to other more modern fluoroquinolones such as enrofloxacin. In Great Britain nalidixic acid resistance in salmonellae was rare and sporadic until 1994, when increasing resistance in DT 104 isolates was noted in most of the livestock species except ducks and sheep. By 1995 there had been a rapid increase in the proportion of resistant *S. typhimurium* isolates from turkeys and a more gradual increase, largely as a result of increasing resistance in DT 104, in isolates from other species (Davies et al, 1999). In 1997, 72.7% of other *S. typhimurium* DT 104 isolates from turkeys were resistant to nalidixic acid compared with zero and 16.1% from chickens.

In the United States multidrug-resistant *S. typhimurium* DT 104 has been isolated from cattle, sheep, goats, pigs, wild birds, dogs, cats, mice, and horses. Serotyping, phage typing, and antibiograms must be performed to identify isolates as DT 104.

Compared with most other countries, antimicrobial resistance among *Salmonella enterica* isolated from Danish pig herds is uncommon (Baggesen and Aarestrup, 1998) and the number of multiresistant isolates is still small. The prevalence of multiple-resistant *S. typhimurium* DT in Danish pig herds is still low.

In Denmark the frequency of antimicrobial resistance and epidemiological relatedness among 473 isolates of *S. enterica* spp. *Enterica* serovar typhimurium from humans and veterinary sources has been examined (Seyfarth et al, 1997). The human strains were isolated from patients with diarrhea and the animal strains from clinical and subclinical infections in cattle, pigs, or poultry. All strains were tested against 22 antimicrobials used in both human and veterinary medicine with the tablet diffusion method. Strains were phaged typed and the plasmid content determined in all resistant strains. Ribotyping was performed on selected strains. Of 228 human isolates tested, 19.3% of the strains were resistant to one or more antimicrobials compared with 10.4% of strains from cattle, 11.1% of strains from pigs, and 9.2% of strains from poultry. Multiple resistance to at least four antimicrobials was found in 9.2% of the human strains, but in only two of the cattle isolates. The majority of the multiresistant strains in humans were from infections contracted outside Denmark, most often in southern Europe or southeast Asia. Resistance in human strains was most common against tetracycline (13%), ampicillin (12%), sulfonamide (12%), streptomycin (10%), and chloramphenicol (8%). The resistance pattern differed somewhat in animal isolates. Poultry strains usually were resistant only to ampicillin, whereas pig and cattle isolates were most often resistant to sulphonamides, tetracycline, and streptomycin. Typing of the strains found some animal strains and human strains were indistinguishable.

Antimicrobial use in swine production is associated with increased resistance to those antimicrobials among fecal *E. coli* 0157:H7of finisher pigs (Dunlop et al, 1998b). Antimicrobial treatment of groups of pigs was more important than individual medication in increasing the risk of resistance among *E. coli* 0157:H7, but there was little evidence that group treatment practices increased the risk of resistance to gentamicin, which was used only for individual animal therapy. Antimicrobial use in starter rations was associated with resistance to ampicillin, carbadox, nitrofurantoin, sulfisoxazole, and tetracycline. Antimicrobial use in grower-finisher rations was significantly associated with resistance to ampicillin, spectinomycin, sulfasoxole, and tetracycline. The results suggest that antimicrobial medication of rations of postweaning pigs selects for and maintains antimicrobial resistance among *E. coli* 0157:H7 of finisher pigs. Antimicrobial resistance was also common on farms that did not medicate rations of postweaning pigs; the results indicate that antimicrobial use does increase the risk of resistance to antimicrobials studied. It was concluded that reducing group medication with broad-spectrum antimicrobials of weanling and grower-finisher pigs might reduce the prevalence of resistant *E. coli* 0157:H7 in market pigs. Thus antimicrobials should be used only when necessary, and the swine industry should continue to invest in the maintenance of a healthy population of pigs in which the need to treat with antimicrobials is reduced.

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Information on the use of feed additives in swine herds was collected from 710 farms (Dewey et al, 1997). Of all the feeds, about 79% contained feed additives used in the labeled manner. For all classes of pigs, the prevalence of labeled feed additive use was greater than 75%. Penicillin was used according to its label most often, followed by apramycin, bacitracin, tetracyclines, lincomycin, and tylosin. Carbadox had the highest prevalence of off-label use. Of the 699 feeds that included feed additives in an off-label manner, about 57% included additives at greater than the recommended concentrations or were fed to an incorrect class of pig. About 56% of the feeds had off-label combinations of additives. Small farms were more likely to use rations with no feed additives than were intermediate or large farms. Of those farms using feed additives, the odds of a small farm using all feed additives in the labeled manner was 7.7 times that of an intermediate or large farm. After controlling for herd size, producers who used a veterinary consultant were 2.1 times more likely to use feeds with feed additives.

Zoonoses

Some infectious diseases of food-producing animals are zoonoses, and the veterinarian has a vital role in ensuring that these diseases are controlled in animal herds so that spread to the human population does not occur. Rabies is one of the world's most important zoonotic disease, killing an estimated 35,000 people annually mostly in China and India (Frost and Hamir, 1998). It is an economically significant disease in livestock in areas where vampire bats are common, such as in South and Central America and the Caribbean. Raccoons are known to be a long-standing reservior for the virus in the southeastern United States, and the more recent outbreaks, in the 1990s, in the mid-Atlantic and northeastern states are the result of the translocation of infected animals from the southeast (Smith, 1996).

Examples of zoonotic diseases from food producing animals include tuberculosis, Q fever, listeriosis, chlamydiosis, brucellosis, and cryptosporidiosis. In recent years, tuberculosis in red deer caused by *M. bovis* has become a disease of economical as well as public health importance to the deer farming industries of several countries, especially in Denmark, Sweden (Wahlström et al, 1998), New Zealand, and the United Kingdom (Clifton-Hadley and Wilesmith, 1991). Orf, or contagious pustular dermatitis, is a zoonotic skin disease of sheep and goats caused by a parapox virus. In a survey in England, 27% of those employed or living on a sheep farm reported having had orf, and the antibody serological profiles indicated a prevalence of 4% and an annual incidence of 2.8% (Paiba et al, 1999). The main risk factors associated with the infection were contact with sheep, the size of the flock, and contact with dogs. Ringworm is still a common occurrence in family members exposed to cattle with the disease. Protection of the consumer from zoonoses transmitted through animal products depends on the efforts of veterinarians to provide advice for the control of disease on the farm and to increase the emphasis on meat inspection in abattoirs. In some cases eradication of the disease from the herd is necessary to prevent spread to humans. Veterinarians are often the first to identify diseases in farm livestock and have a unique opportunity to offer advice on the prevention of human disease through the emphasis of personal hygiene and the avoidance of raw milk consumption.

Foodborne Illness

Foodborne illness is a major public health concern in many countries. The largest potential sources of harm in foods are microbiological contamination and nutritional imbalance, in that order. In the United States, estimates of the incidence of human foodborne illness range from 6.5 to 33 million cases annually, with about 9000 fatalities (Petersen and James, 1998). Meat and eggs are commonly implicated vehicles, and *Salmonella* spp. and *E. coli* 0157:H7 account for about 50% of agents reportedly isolated (Petersen and James, 1998). The cost of diarrheal foodborne illness alone has been estimated as $3.5 to $17 billion annually (McCapes et al, 1991). In Ontario, salmonellosis, *Campylobacter* enteritis, and yersiniosis are the most commonly reported zoonoses that occur in people living on family farms. Infection can occur after the consumption of raw milk or contaminated well water or after contact with livestock.

The most important pathogens that occur daily are *Salmonella* spp., *E. coli* 0157:H7, and *Campylobacter jejuni.*

Salmonella spp.

The *Salmonella* species are one of the most common foodborne pathogens. Economic costs associated with human salmonellosis are nearly $1 billion annually in the United States.

Humans can become infected by most serotypes of *Salmonella.* In the United States, the most common serotypes among isolates recovered from humans annually are *S. typhimurium, S. enteritidis, S. heidelberg, S. hada,* and *S. newport.* Poultry are the food animal reservoir for *S. enteritidis,* and eggs provide a source of the organism for humans. Cattle are the reservoir for *S. newport* and *S. dublin. Salmonella* is also an important pathogen to cattle, and the organism can be found in the feces of about 5% of feedlot cattle (Losinger et al, 1997).

S. typhimurium is not host specific and is equally infectious to both animals and man. Infection with salmonella does not always cause clinical disease. A localized gastroenteritis is most common, and spontaneous recovery without treatment is common. The very young and elderly, immunocompromised patients, and those already taking oral antimicrobial medication are most at risk of developing systemic illness with septicemia.

Escherichia coli

Several different virotypes of *E. coli* 0157:H7 can cause disease in humans and animals (Su and Brandt, 1995). The most important one causing disease in humans is the enterohemorrhagic type (EHEC) known as *E. coli* 0157:H7, a verocytotoxigenic type (VTEC), which causes hemorrhagic colitis (HC) and the hemolytic uremic syndrome (HUS) (Whipp et al, 1994).

Serotype *E. coli* 0157:H7 is classified as an enterohemorrhagic *E. coli* because it causes hemorrhagic colitis, produces a verotoxin Shiga-like toxin, does not produce either heat-stable or heat-labile toxin that is characteristic of enterotoxigenic *E. coli,* and it is not invasive. *E. coli* 0157:H7 is considered the epidemic strain because it has been responsible for major outbreaks reported in the United States, Canada, and the United Kingdom (Whipp et al, 1994; Dorn, 1995).

Cattle are a source of *E. coli* 0157:H7, which causes foodborne disease in humans in North America, Europe, and the United Kingdom. Transmission of the organism occurs through the ingestion of *uncooked* ground beef and consumption of raw milk, although outbreaks have been associated with fresh-pressed apple cider, unchlorinated drinking water, and person-to-person transmission. Investigations of outbreaks of disease in man have linked most of the cases to consumption of hamburgers from fast-food restaurant chains. *E. coli* 0157:H7 was isolated from ground hamburger

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supplied to restaurants by meat suppliers. This was followed by recall of the incriminated meat (Dorn, 1993).

While the herd prevalence of infection may vary from 50% to 75% depending on geographical location, the prevalence of *E. coli* 0157:H7 in the cattle population is low. In a survey in the United States, the prevalence in dairy heifers and in all cattle was 0.37% and 1.85%, respectively. Person-to-person spread also occurs. Overall, *E. coli* 0157:H7 was recovered at higher rates from pens of cattle that had been on feed for the shortest period of time (3.01%). Samples from pens of cattle that had been on feed the longest time and were closer to slaughter were less likely to give positive results for *E. coli* 0157:H7 (1.08%) (U.S. Department of Agriculture, 1995). Other studies found that 0.33% of the fecal samples and 10% of feedlot pens sampled gave positive results for *E. coli* 0157:H7 (Hancock et al, 1994).

Contamination of carcasses during slaughter and processing may explain how beef and beef products become contaminated and thereby transmit the organism to man. The organism can survive in bovine feces for long periods and still retain its ability to produce verotoxins (Wang et al, 1996). In vitro studies of the growth of the organism in rumen contents indicate that the organism does not grow well in rumen fluid collected from fasted cattle, suggesting that well-fed animals appear less likely to become reservoirs for pathogenic *E. coli* 0157:H7. The organism has been isolated from dairy calves less than 8 weeks of age, and calves were 3 times more likely to shed the organism after weaning than before weaning (Garber et al, 1995).

The persistence of *E. coli* O157:H7 in dairy cattle is transient, and persistence of the organism cannot be demonstrated from farm environment sites tested. The duration of detected *E. coli* O157:H7 by individual cattle is usually less than 1 month. In Washington State, the organism was found in 0.28% of fecal samples from dairy cattle in 8.3% of herds. Fecal samples, bulk milk samples, and milk filters were negative for the organism. The strain was also isolated from 0.71% of fecal samples from pastured cattle of 16% of herds sampled. The organism has also been isolated from the feces of cattle and deer on a ranch in Texas, which suggests that wild ruminants may shed verocytotoxic *E. coli* O157:H7. In beef feedlots the prevalence was 0.33%. Drinking water on dairy farms in Wisconsin has also been identified as one source.

E. coli 0157:H7 is not resistant to antimicrobials and is not used for the treatment of patients clinically affected with the disease.

Epidemics of HC and the HUS in humans infected with *E. coli* 0157:H7 have been attributed to the consumption of ground beef, which potentially could have originated from cattle infected with the strain of the organism. Verotoxin-producing strains of *E. coli* 0157:H7 known to be pathogenic for humans have been isolated from the feces of healthy cattle.

Campylobacter jejuni

Campylobacter jejuni is a common foodborne pathogen and a leading cause of foodborne disease in humans in the United States and other industrialized countries (Altekruse et al, 1998). Most outbreaks are associated with raw milk or surface water, whereas most sporadic cases are often associated with mishandling and consumption of undercooked poultry or cross-contamination of foods by raw poultry. Most retail chicken for human consumption contains *C. jejuni*. The organism may be present in bulk milk samples, tissue specimens of beef cattle, and raw ground beef. Other foods associated with campylobacteriosis include barbecued sausage and shellfish. The organism can be found in poultry, cattle, pigs, sheep, and other food animal species. Several species of birds and rodents may also carry the organism.

Bovine Spongiform Encephalopathy and New Variant Creutzfeldt-Jakob Disease in Humans

Bovine spongiform encephalopathy (BSE) was recognized in cattle in the United Kingdom in 1986, causing major economic costs and international controversy about the safety of beef as a human food (Bruce et al, 1997). The Phillips Inquiry into the emergence and identification of BSE and variant Creutzfeldt-Jakob disease (vCJD) and the action taken in response to it up to March 20, 1996 was handed to the government on October 2, 2000 (BSE Inquiry, 2000). As a result of over 2 years of inquiry, the report comprises 16 volumes containing findings and conclusions. It is now accepted that the new vCJD in humans in the United Kingdom is directly linked to the epidemic of BSE first described in 1986. It is probable that humans affected with vCJD became infected from eating beef products containing the prions that cause the disease. In recognition of this, beef products with risk for infectivity were banned for human consumption early in the outbreak, and the list was enlarged as further information on infectivity of by-products became known. The occurrence of this disease has also resulted in a public questioning of the safety of cattle products as human food and a shift in the dietary habits of concerned people. The threat of the human disease resulted in a significant fall in beef consumption and prices. In response to market forces, the United Kingdom instituted a compulsory slaughter of at-risk, but healthy, cattle, with significant economic and social costs.

Livestock Production in Developing Countries

Infectious diseases of livestock are a major impediment to livestock production and economic development in Africa (Jawara, 1990). The tropical climate is extremely conducive to the growth and propagation of pathogens, and consequently the environment is rife with diseases and their vectors. The major diseases affecting livestock are rinderpest, foot-and-mouth disease, contagious bovine pleuropneumonia, theileriosis, and trypanosomiasis. Helminth infections are significant and are a cause of high mortality in young animals. Ticks are also a major cause of disease in Africa. Tick infestations directly depress the productivity of livestock, but, more importantly, they are vectors of diseases such as East Coast fever or theileriosis, babesiosis, anaplasmosis, heartwater, and streptotrichosis. Streptotrichosis is a primary production-limiting disease of cattle in humid areas. Trypanosomiasis is one of the most important diseases in the subhumid and humid tropics of Africa (Jawara, 1990). It is obvious that animal diseases are a major constraint on the economic development of Africa, and effective control depends on well-trained and educated personnel, availability of resources, and a much-needed interdisciplinary approach. Considerable research efforts are being carried out by many different agencies in regard to the economic control of these infectious diseases (Jawara, 1990).

Problems with Exportation and Importation

Certain diseases, such as brucellosis, enzootic bovine leukosis, pseudorabies, and bluetongue, interfere with the exportation of breeding livestock to countries requiring that imported animals be certified free of pathogens that cause certain diseases. In some cases, as with enzootic leukosis, there is evidence that the disease may have been introduced into England from unknown infected cattle imported from Canada. Scrapie in sheep certainly has been spread internationally by the movement of infected sheep.

Previously unrecognized infectious diseases may emerge unexpectedly in a region or country and can create considerable and expensive veterinary diagnostic laboratory activity and public health concern. The recognition of BSE in Eng-

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land in 1986 and the potential risk that the beef could be the source of the agent causing vCJD in humans was one of the most important zoonotic concerns in the last decade (Bruce et al, 1997). There is evidence that the biological and molecular transmission characteristics of vCJD are consistent with it being the human counterpart of BSE (Hill et al, 1997). The disease was declared a notifiable disease, affected cows were slaughtered, and compensation was paid to the owners. These actions by regulatory authorities are often made into sensational news stories, which can have a marked adverse effect on the sales of meat and milk.

The fact that some diseases have been brought under control or eradicated in some countries may create a false sense of security, and this could result in less emphasis on surveillance, the introduction of infected animals into the country, and the spread of the disease before it is detected. Examples include brucellosis, tuberculosis, and enzootic bovine leukosis. The potential for new infections requires a reliable surveillance system that prevents the entry of infected animals. The state of Texas achieved class "A" brucellosis status in 1994 and is approaching eradication status. Brucellosis is recognized as one of the most important zoonotic diseases in Mexico because of the economic and public health implications. Since Texas is the primary export market for cattle from Mexico, the importation of sexually intact cattle originating from breeding herds in Mexico could provide a source of infection (Brown and Hernández de Anda, 1998a). This necessitates a strict import sanitary requirement to mitigate the potential risk of transmission of brucellosis from sexually intact cattle of Mexican origin to Texas cattle. Tuberculosis in steers imported from Mexico into the United States is an important animal health issue for the livestock industry (Brown and Hernández de Anda, 1998b). In some years, about 70% of all tuberculosis cases in cattle in the United States were in cattle originating from Mexico. The overall prevalence of tuberculosis at slaughter in adult beef cattle that originated in Mexico was approximately 0.5/1000.

Carcass Condemnations

Infections such as arthritis and pneumonia are a major reason for the condemnations of cattle and swine in abattoirs in the United States. The treatment and control of infectious diseases in food animals may involve the intramuscular injection of antimicrobials and vaccines, which can result in a significant prevalence of *injection site lesions*. When these lesions occur in valuable cuts of meat, they must be trimmed at processing, the cuts are devalued, and there may be consumer dissatisfaction from eating tough beef. These defects in quality constitute a significant economical loss to the cattle industry (Van Donkersgoed et al, 1997; Van Donkersgoed et al, 1998a; Van Donkersgoed et al, 1998b; Van Donkersgoed et al, 1999a). Pharmaceutical companies have been developing animal health products that can be administered subcutaneously, orally, or topically, rather than intramuscularly.

CAUSES OF INFECTIOUS DISEASES

Specific Infectious Diseases of Food-Producing Animals

Some examples of infectious diseases of food-producing animals that may cause herd problems include the following.

Cattle

The common diseases of cattle are contagious and environmental mastitis, acute undifferentiated diarrhea of newborn calves, pneumonic pasteurellosis, infectious abortions, viral interstitial pneumonias, salmonellosis, winter dysentery, footrot, pinkeye, leptospirosis, coccidiosis, intestinal helminthiasis, ectoparasitism, and ringworm. The less common diseases include anthrax, brucellosis, hemophilus septicemia, infectious bovine rhinotracheitis, bovine virus diarrhea, rabies, anaplasmosis, cowpox, and pseudocowpox. Uncommon diseases include tuberculosis, paratuberculosis, pseudorabies, bluetongue, bovine malignant catarrh, enzootic bovine leukosis, BSE, and clostridial diseases. In Africa, rinderpest, foot-and-mouth disease, trypanosomiasis, contagious bovine pleuropneumonia, theileriosis, and helminthiasis are major diseases of cattle.

Swine

The common diseases of swine are acute diarrhea of piglets caused by *E. coli* 0157:H7 and transmissible gastroenteritis virus, postweaning diarrhea, *Streptococcus suis* infection, mastitis, enzootic pneumonia, porcine reproductive and respiratory syndrome, hemophilus pleuropneumonia, atrophic rhinitis, swine dysentery, leptospirosis, and intestinal helminthiasis. Less common diseases include pseudorabies, exudative epidermitis, swine influenza, and ectoparasitism. Exotic diseases of swine include hog cholera, African swine fever, swine vesicular disease, and vesicular exanthema.

Sheep

The common diseases in sheep are footrot, intestinal helminthiasis, ectoparasitism, pasteurellosis, enzootic abortion, caseous lymphadenitis, and maedi-visna. Less common diseases include bluetongue, scrapie, border disease, contagious ecthyma, clostridial diseases, and leptospirosis.

The successful control of any infectious disease depends on a knowledge of the causes of the disease; this includes the specific pathogen or combinations of different pathogens that are considered to be the cause of the lesions of the disease. The epidemiological determinants or predisposing risk factors related to the host or the environment, such as age, stress, lack of immunity, and breed susceptibility, that contribute to the development of the disease are also considered as causative factors.

Etiological Agents

The infectious diseases of major concern in food-producing animals are those caused by bacteria viruses, protozoa, helminths, and ectoparasites. Diseases caused by mycoplasma are of lesser importance. The diseases that appear to cause the greatest economic loss, particularly under conditions of intensive production, are those that affect the mucosal surfaces of the body, such as the gastrointestinal tract, respiratory tract, mammary gland, reproductive tract, skin, conjunctiva, and eyes. Some diseases, such as clostridial infections, occur uncommonly because of the use of effective vaccines; some, such as mucosal disease, occur sporadically. Others, such as subclinical mastitis in dairy herds, are endemic. Pneumonia in feedlot cattle is a common occurrence in recently arrived cattle. A disease such as acute undifferentiated diarrhea of newborn calves occurs in most herds of cattle as sporadic epidemics, resulting in high morbidity and mortality.

Some diseases, such as rabies, are *causally defined* and are caused by a single pathogen, the rabies virus. However, many common infectious diseases of the respiratory and digestive tracts of food-producing animals are not causally defined but are *multifactorial* disease complexes caused by two or more pathogens, with or without predisposing causes or risk factors. Diarrhea and pneumonia can be caused by any one of or a combination of several pathogens, but the mere presence of the pathogens in those body systems does not necessarily cause disease. A *necessary cause* of disease is one

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without which the disease cannot occur. The rabies virus is a necessary cause of rabies. However, although *M. haemolytica (P. haemolytica)* is a necessary cause of pneumonic pasteurellosis, it is not a necessary cause of pneumonia. Enterotoxigenic *E. coli* 0157:H7 is a necessary cause of enterotoxigenic colibacillosis but not of diarrhea. In contrast to a necessary cause, a *sufficient cause* is one that always produces the disease. Single factors are infrequently sufficient causes. Almost all sufficient causes are composed of a grouping of factors, each called a component cause; thus many diseases can have a multifactorial cause (Martin et al, 1987). By definition, necessary causes are a component of every sufficient cause. Generally speaking, *M. haemolytica (P. haemolytica)* is the cause of pasteurellosis in cattle. However, a sufficient cause of pasteurellosis requires the presence of other factors, such as stress, a preceding viral infection, or lack of immunity, as well as the presence of the organisms in the lung, before the disease can occur. It must be emphasized that the mere presence of the organisms in the respiratory tract is not sufficient cause for the disease to occur. It has been suggested that acute undifferentiated bovine respiratory disease occurs in feedlot cattle that have been stressed (Ribble et al, 1995a; 1995c). It may be more effective to attempt control by identifying and minimizing the stress factors rather than by relying on specific control measures, such as vaccination or mass medication, which are aimed principally at the pathogens thought to be important (Martin et al, 1988).

Can a necessary cause also be a sufficient cause of disease? The rabies virus is the necessary cause of rabies. Is it also a sufficient cause? Not all animals that are bitten by a rabid animal develop rabies, but rabies probably occurs more commonly in exposed, unvaccinated animals than in vaccinated animals.

A *multifactorial* disease can be defined as one that requires the interaction of more than one infectious agent or of one or more infectious agents with other factors to produce disease. In many infectious diseases of the respiratory and digestive tracts of food-producing animals, mixed infections occur in which two or more pathogens act cooperatively or synergistically. In those cases, host or environmental risk factors increase the susceptibility to clinical disease. For example, *M. haemolytica (P. haemolytica)* may be the ultimate cause of most cases of acute respiratory disease in feedlot cattle. However, it has been hypothesized that respiratory viruses such as parainfluenza-3 (PI-3), infectious bovine rhinotracheitis (IBR), bovine respiratory syncytial virus (BRSV), or other viruses or environmental stressors may decrease the resistance of the animal, which allows the *Pasteurella* organisms to colonize the lung and produce the lesion. Experimentally, a viral infection of the lung can inhibit lung clearance mechanisms and interfere with alveolar macrophage function, which allows the *Pasteurella* organisms to colonize, produce leukotoxin, and initiate the inflammation. It can be difficult to reproduce pneumonic pasteurellosis experimentally solely with the bacteria unless the lower respiratory tract is swamped with the bacteria, but experimental aerosol respiratory viral infection preceding an aerosol bacterial challenge is usually more successful.

Herd outbreaks of disease occur commonly in which the etiology is uncertain but evidence of seroconversion to certain infectious agents in association with clinical disease may indicate a causal relationship. For example, outbreaks of bovine respiratory disease in western Europe have been associated with seroconversion of lactating dairy cattle to influenza A virus in association with respiratory disease and reduced milk yield (Brown et al, 1998). Similarly, a syndrome of milk drop, body condition loss, and respiratory signs, often accompanied by abortion in dairy herds, was associated with significant seroconversion to *Chlamydia* spp. (Dannatt et al, 1998). These are examples of herd epidemics of disease of unknown etiology, but the seroconversion of affected animals to certain infectious agents may provide evidence of a causal relationship and the need to investigate the cause-and-effect relationship.

In acute undifferentiated diarrhea of newborn calves, mixed infections with enterotoxigenic *E. coli* 0157:H7, rotavirus, coronavirus, and *Cryptosporidium parvum* may occur in up to 30% of affected calves and in some normal calves in the same population. The pathogenetic mechanisms that result in clinical disease in some calves and not in others in the same population are not well understood. Inadequate colostral immunity, however, is an important risk factor.

The diagnosis, clinical management, and control of multifactorial disease complexes can be difficult because of the uncertainty of the role of each pathogen or risk factor. For example, the interpretation of the presence of a mixture of pathogens in the lungs of cattle that have died from pneumonia and have been treated with antimicrobial drugs can be difficult. The reliability of making causal inferences about the isolation of a pathogen from clinically affected animals can be improved by the submission of samples from normal animals kept in the same environment as the affected ones (Martin et al, 1987). Without knowing which pathogen is most important, it is difficult to formulate an effective vaccination program. Furthermore, it is usually difficult to determine which of the many host and environmental risk factors are most important so that they can be minimized or removed if they are sufficient causes. The control of many infectious diseases of food-producing animals has been difficult because the evidence that certain risk factors are important has been empiric and based on crude field observations. Qualitative and quantitative epidemiological techniques are now available to help plan and carry out meaningful observational studies, which can identify and quantify risk factors according to their relative importance. The most important risk factors then can be minimized or removed and can result in a decrease in the incidence of disease. The successful control of a multifactorial disease also requires the simultaneous manipulation of several management practices. For example, the control of bovine mastitis caused by contagious pathogens depends on good milking technique, postmilking teat dipping, dry cow therapy, and culling of chronically infected cows. Constant surveillance of the somatic cell count (SCC) and culturing milk samples to detect infected cows are important, as are good sanitation and hygiene practices in the dairy barn.

A number of methods can be used to study the causal relationships of disease and to evaluate risk. They include simple, descriptive epidemiological methods and study designs, such as case control studies, prospective and retrospective cohort studies, and cross-sectional studies. Statistical techniques include 2×2 tables, regression analysis, path analysis, discriminant analysis, and analysis of variance. The difficulty of obtaining a definitive, causative diagnosis for a problem such as bovine abortion in dairy herds has prompted the development of an innovative epidemiological approach. A computer-based, on-farm surveillance system of dairy cow abortion has been developed, which may help in the diagnosis and provide more information about abortion (Thurmond and Picanso, 1990). The frequency of occurrence of abortions is calculated as the number of abortions observed during a specified period divided by the sum of cow-days at risk for that period. The abortion density could be used to determine the risk of abortion during each month of the year. Etiological agents are isolated in only about 33% of aborted fetuses, and lesions are detectable in only about 12% (Agerholm et al, 1997).

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In summary, infectious diseases of food-producing animals are caused by many different infectious agents that act singly or as a mixed infection, with or without predisposing factors, which render the animals susceptible to infection and clinical disease. The identification and elimination or minimization of the risk factors are important in the control of disease.

EPIDEMIOLOGY OF INFECTIOUS DISEASES

Epidemiology may be defined as the study of the patterns of disease that exist under field conditions (Martin et al, 1987). Martin et al (1987) said, "More specifically, epidemiology is the study of the *frequency, distribution,* and *determinants* of health and disease in populations." In other words, epidemiology is the study of how frequently the disease occurs, where and when it occurs, which animals it affects, and the determinants or causes of diseases in populations of animals. A comprehensive understanding of the epidemiological characteristics of a specific infectious disease, including its natural history, is a prerequisite to the formulation of control procedures. Qualitative epidemiology deals with the details of the transmission, maintenance, and ecology of infections and infestations. Quantitative epidemiology requires an understanding of basic observational techniques, such as sampling and measurement of association. This enables practitioners to separate random variation in levels of production from decreases in productivity caused by disease in intensive livestock enterprises. An understanding of economic theory and statistics is also necessary for the formulation of economical disease control programs and to set priorities. This requires a major reorientation of the traditional veterinary curriculum, away from the exclusively individual animal approach to one that is both individual animal and population based. New approaches to animal health problems include more science than art and more of a mathematical or observational approach than an experimental one. The application of clinical epidemiology to veterinary practice is an imposing challenge. However, once veterinarians become familiar with the application of epidemiological parameters, such as sensitivity, specificity, prevalence, positive and negative predictive values, and odds ratios, the diagnostic accuracy and clinical management of disease will be enhanced.

The *natural history* of an infectious disease includes the method of transmission from infected to susceptible animals, the portals of entry into the body, the incubation period, the distribution of the infectious agent within the body, the immune response of the animal to the infectious agent, its persistency or latency in body tissues, and the frequency and persistency of shedding of the pathogen. These are all important in the spread and persistence of infection in a population. Persistent infections of individuals, even when shedding occurs only sporadically, can form important reservoirs of infection. Typical examples include young cattle persistently infected with the bovine viral diarrhea virus, long-term shedders in cattle and pigs affected with leptospirosis, and the persistent infection that is possible with footrot in sheep. Horizontal transmission can occur by direct or indirect contact through inanimate fomites, mechanical or biological vectors, or other species acting as a reservoir. Ticks are important vectors for several major infectious diseases of livestock. Infections can also be transmitted vertically from dam or sire to offspring either congenitally or, for some retroviruses, genetically. A knowledge of the life cycles of internal and external parasites is also important for the formulation of effective parasite control programs.

Risk Factors

Although there are many different pathogens that are ultimately the cause of subclinical or clinical disease, the risk factors that contribute to its cause and distribution are often more important as a foundation for the formulation and application of control measures. The *host, environmental and managemental,* and *pathogen* risk factors of a disease are the characteristics that interact to contribute to the development of the disease. Some of the examples used here illustrate the interdependence among many risk factors, and often it is controversial whether a particular risk factor belongs in one or more of the three categories.

Host Risk Factors

Factors that influence or control a host's susceptibility to infection, or if it is infected, that determine the development of disease, are called host risk factors. These factors include *age* at infection, *size of herd, nutritional status, immunity status, preexisting disease in the herd, stage of pregnancy and production,* and *breed.*

Age of Animals. The level of colostral immunity in newborn farm animals is a major determinant of resistance against neonatal disease in addition to survival from clinical disease, such as neonatal diarrhea. Many factors influence the amount of colostral immunoglobulins absorbed by the calf, including how much colostrum it ingests, how soon after birth the colostrum is ingested, the concentration of immunoglobulins in the colostrum, the maternal behavior of the dam, and the vigor of the calf. Postnatal respiratory acidosis in newborn dairy calves can adversely affect colostral immunoglobulin absorption, despite colostrum intake early in the postabsorptive period (Besser et al, 1990). Several infectious diseases of the intestinal tract are more common in newborns because of their high susceptibility, whereas with other diseases, such as enzootic pneumonia of pigs, the incidence increases with the age of the pig. This is probably a reflection of prolonged exposure (Gardner and Hird, 1990). Most severe respiratory disease from primary infections of BRSV occurs in calves under 5 months of age (Van der Poel et al, 1993). Calves can become reinfected but seldom develop disease after reinfection, which is more common in adults.

Size of Herd. The size of the herd may be a risk factor. Large herd size (at least 500 sows) significantly increases the odds of positive transmissible gastroenteritis serostatus compared with herds of 100 to 199 sows (Yanga et al, 1995). In large herds there are frequently more contacts with potential sources of infection, such as feed and pig transport trucks entering the premises. In large breeding herds some susceptible females may not be exposed to infection during a primary outbreak of disease, and these females fail to transfer adequate colostral antibodies to nursing piglets that are at greatest risk of infection. In large herds that are expanding, there may be greater odds of infected animals because the absolute number of replacement females increases as herd size increases. Theoretically, a larger pool of susceptible females facilitates circulation of the virus and hence the persistence of infection in the herd. However, transmission of a virus infection in a herd may be independent of the size of the population, providing that groups of animals are housed at equal density (Bouma et al, 1995).

Nutritional Status. Although the subject is somewhat controversial, some workers have claimed that the presence of a *nutritional deficiency* of copper or selenium may increase susceptibility to infection. There is some evidence that copper deficiency associated with increases in molybdenum on pasture may increase the susceptibility of certain genetic lines of lambs to microbial infections. There is much interest

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in the observations that supplementation of the diet of dairy cows with selenium can reduce the incidence of mastitis and lower the SCC. Selenium deficiencies have been reported to suppress the immune response in various species, and the selenium status can affect IgM concentrations following stress. However, many of these observations on the effect of deficiencies on the immune system of animals are based on experimental work. Whether these deficiencies constitute a risk factor in naturally occurring infectious diseases has yet to be determined.

Immunity. In general, nonimmune animals are more susceptible to infectious clinical disease than animals that are immune as a result of adequate vaccination or natural infection. For example, the percentage of beef cow-calf herds in the United States that are naive to BVDV is small (Paisley et al, 1996). More than 90% of herds and more than 65% of animals have been exposed to BVDV either through vaccination or natural exposure. Thus it is unlikely that large epidemics would occur. The risk of morbidity and mortality or reproductive loss in individual nonimmune animals and herds could be large if the virus was introduced, but the number of these herds appears to be small. The vaccination of breeding and finishing swine herds aids in the eradication of pseudorabies infection (Lehman et al, 1993). Outbreaks of infectious disease, such as those due to BRSV, may occur in cattle herds in which the herd immunity has waned over time and certain unidentified factors precipitate increased replication, or a change in virulence, and shedding of the pathogen, resulting in clinical disease (Ellis et al, 1996b). In dairy herds affected with winter dysentery, cow-level risk factors for the development of the disease have been evaluated. Cows with the clinical disease were more likely to shed detectable amounts of bovine corona virus antigen in their feces, and pregnancy appeared to protect cattle from the disease (Smith et al, 1998b). The likelihood of developing disease in individual cows increased as the enzyme-linked immunosorbent assay (ELISA) value for bovine coronavirus antigen detectable in feces increased. Cows with high acute bovine coronavirus antibody titers that seroresponded had greater odds of developing disease, compared with seroresponding cows with low acute titers. The immune factors that appeared to increase a herd's risk of winter dysentery included an increase in the herd prevalence of adult cows that had a fourfold or more increase in bovine coronavirus serum IgG antibody titer and an increase in herd prevalence of adult cows that had a fourfold or more increase in BVDV.

Varying degrees of *immunosuppression* can be measured experimentally in animals affected with infectious agents, including bacteria, viruses, parasites, and fungi, and by noninfectious factors, such as malnutrition, stress, and weaning. However, whether a preexisting immunosuppression is a significant factor in most cases of common, naturally occurring infectious diseases is unknown.

Preexisting Disease in the Herd. Host risk factors for certain diseases may be related to the presence of disease and other host variables existent in the herd. An examination of the risk factors for clinical mastitis in dairy heifers found that a relationship between the risk of mastitis for heifers and the total incidence rate for clinical mastitis in the corresponding herd, a decrease in the bulk milk SCC, an increase in the mean milk yield, and an increase in age at first calving (Waage et al, 1998). A high overall herd incidence rate for clinical mastitis may reflect the presence of a prevalent reservoir of contagious udder pathogens in the herd and, thus, increased risk of exposure of the heifers to such pathogens. Milk leakage was also associated with an increased risk for mastitis.

Stage of Pregnancy or Production. There is a close relationship between foul-in-the-foot (interdigital dermatitis) and calving in Danish dairy cows (Alban et al, 1995). This relationship may be associated with the abrupt metabolic and environmental changes that are associated with calving. The cow's incidence risk of the disease was 0.6% during the first month postpartum, which was 6 times higher than in the last month prepartum and in any other month postpartum. Almost half of the first treatments for the disease were in the first 30 days postpartum.

Breed. Certain *breeds* of animals may be more susceptible to some specific infections than others, but this is not well documented.

Environmental and Management Risk Factors

Environmental and management risk factors include wind, rain, snow, adequacy of ventilation and air quality (including concentrations of dust, noxious gases, and relative humidity), population density, comfort of housing, level of contamination of bedding with pathogens, level of animal management and care given to animals, handling methods used to treat animals, and other management strategies that can contribute to an increased susceptibility to infectious disease or can make the occurrence of disease possible. These risk factors, alone or in combination, can play an important role in predisposing to infectious disease. The veterinarian should attempt to identify these risk factors and make producers aware of them so that disease can be prevented or minimized. Some examples are outlined here.

Housing Conditions. Respiratory diseases are common in swine raised under intensive housing conditions and represent one of the most prevalent and costly health problems in pig production worldwide. For each 1% of lung affected by enzootic pneumonia, there can be a significant reduction of average daily gain and an increase in the number of days to market. Surveys of lung lesions and risk factors for respiratory diseases in swine herds have found a relationship between environmental factors related to housing and management of the farm (Stark et al, 1998). In particular, factors related to stocking density and air quality such as manure management and general hygiene are highly influential. Among the various control measures, the development of specific pathogen free herds has been most effective. However, these herds also have difficulties in maintaining their disease-free status in regions with high pig densities, short farm-to-farm distances and complex trade structures (Stark et al, 1992).

Factor analysis of swine farm management practices can be used to examine the role of risk factors in respiratory disease (Hurnik et al, 1994a,b). Management factors can include farm size, growth rate, feeding styles and feedstuffs, manure handling and bedding, ventilation, pen space and flooring, moving and mixing pigs, sources of pigs, people contact in the barn, labor source, and experience. First the factors are identified and then analyzed to determine which factors contribute to disease. The prevalence of disease on farms is then correlated with the presence of the factors and odds ratios calculated. In one example, family farms using floor feeding methods had an odds ratio of 3.31, suggesting that this combination of management styles may be a risk factor in enzootic pneumonia. Integrated farms had an odds ratio of 2.3 for having the disease, suggesting that larger farms that mill their own feed and are closer in proximity to other pig farms have a greater chance of having enzootic pneumonia. A linear regression of the prevalence estimates of enzootic pneumonia on positive farms revealed that only farms with multiple-source feeder barns and floor-fed family farms were associated with a higher prevalence of enzootic

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pneumonia. Farms with extensive pig housing were associated with a lower prevalence, suggesting that farms with ample pen space and air volume had fewer pigs with enzootic pneumonia. Thus many commonly accepted risk factors, in combination, increased the likelihood of enzootic pneumonia (Hurnik et al, 1994a).

Winter dysentery in dairy cattle herds was associated with housing cattle in tie-stall or stanchion barns rather than free-stall facilities as well as use of equipment to handle manure and subsequently handle feed (Smith et al, 1998a).

Hygienic Conditions. An unsatisfactory level of hygiene and sanitation in any animal holding facility can be directly associated with an increase in certain infectious diseases. This principle applies in many situations, such as beef cow-calf herd calving corrals, farrowing crates in swine herds, lambing sheds in sheep flocks, pens in beef feedlots, and dairy calf barns and calf hutches. Clean and dry environmental conditions in dairy herds may be associated with lower bulk-tank SCCs and a lower incidence of clinical environmental mastitis (Bartlett et al, 1992). Dairy herds with designated maternity pens that are isolated and clean have a lower incidence of clinical mastitis. Case-control studies of papillomatous digital dermatitis in dairy farms found that the odds of a higher proportion (>5%) of cows affected were 20 times greater in dairy farms with muddier corrals than in drier dairy farms (Rodriguez-Lainz et al, 1996).

Importation of Animals into a Herd. The importation of replacement breeding animals into a herd is common practice but is often associated with the subsequent occurrence of an infectious disease. Case control studies of papillomatous digital dermatitis in southern California dairy farms found that buying replacement heifers was associated with a 4.7-fold increase in the odds of a higher prevalence of digital dermatitis, compared with dairy farms that did not buy heifers (Rodriguez-Lainz et al, 1996). There was also a positive association between risk and number of heifers purchased.

Geographical Distribution and Density of Herds. The geographical distribution and density of herds can influence the spread of infections. The spread of pseudorabies infection from herd to herd increases with geographical proximity to infected herds (Norman et al, 1996). A decreased density of pseudorabies-quarantined herds in a region was associated with reduced risk of a herd becoming quarantined, whereas increased density of nonquarantined, uninfected herds was associated with decreased probability of a herd becoming quarantined. Decreased density of vaccinated herds was associated with increased probability of a herd becoming quarantined. Using a computerized database linked to a *geographical information system (GIS)*, researchers found that location of a herd within 1 km of a river or lake decreased the risk of pseudorabies infection, and closeness to farrow-to-finish operations, complete confinement, and increasing density of swine herds within a 5-km radius increased the risk of infection (Marsh et al, 1991).

Marketing and Transportation Stress. There is considerable controversy about the effects of marketing and transporting animals, such as feeder calves destined for the feedlot. (Martin et al, 1988). Recent critical studies have shown that when the incidence of fatal fibrinous pneumonia in feedlot calves was high, the disease clustered within truckload groups of calves, within pens, or within both (Ribble et al, 1994). Most of the calves that died of fibrinous pneumonia were sick within 2 weeks of arrival (Ribble et al, 1995b). Transportation itself was not found to be a risk factor, since the risk of fatal fibrinous pneumonia was just as high for calves arriving from nearby markets as that for calves transported much greater distances (Ribble et al, 1995d). Calves entering the feedlot in November had a risk of fatal fibrinous pneumonia 2 to 8 times greater than calves entering in September or December, which was a pattern over a period of 4 years (Ribble et al, 1995a). Several factors could have contributed to this pattern, including changes in transport truck availability, changes in density of calves at markets, changes in population dynamics at the feedlot that affected the feedlot crew efficiency, and weather. There was a positive linear relationship between mixing of calves in truckloads supplied by different buyers and a risk of subsequent fatal fibrinous pneumonia (Ribble et al, 1995c). This suggests that increased mixing of calves from different farms at the auction mart increases the risk of fatal fibrinous pneumonia in calves after their arrival at the feedlot. The incidence of fecal shedding of *Salmonella* sp. in feeder calves can increase, from the time they leave the farm of origin and are moved through auction marts and into the feedlot.

Climatic Changes. Rapid changes in climate, such as a sudden increase or decrease in ambient temperature, increase in relative humidity, snowstorm during calving season in beef herds, or prolonged rainfall causing excessively wet ground surfaces in feedlots, are environmental risk factors. *Inclement weather* and inadequate housing and ventilation often contribute to the onset of epidemics of infectious diseases in farm animals. Several common respiratory diseases of cattle are associated with certain seasons of the year, air temperature, wind, rain and humidity, and air quality. A computerized information retrieval system of slaughter lesions recorded in the abattoir, linked with meteorological data, has been used to investigate the effect of weather conditions on the occurrence of pleurisy and pneumonia in the sheep population of Northern Ireland. Highly significant correlation coefficients were found between the percentage of lung condemnations in sheep and the rain-wind-chill factor prevailing during the same month and 1 or 2 months previously (McIlroy et al, 1990).

Ventilation. Failure of ventilation systems in swine barns during warm seasons can precipitate outbreaks of pneumonia in growing and finishing pigs. The term "environmental medicine" has been suggested to describe the study of the environmental factors that contribute to disease. It is well known that extremely high or low temperatures, extremely high humidity, overcrowding, and other unfavorable rearing conditions lower the production of livestock.

Population Density. Population density is probably the most important factor in intensive animal husbandry influencing the onset of infectious disease in the individual animal and in promoting spread within a group of animals. The mixing of feedlot cattle from different sources on arrival is an important risk-related factor in increasing the morbidity because of lower respiratory tract disease. Persistent problems with environmental mastitis in dairy cattle are associated with inadequate hygiene and sanitation. Growth of organisms in the bedding and on ground and floor surfaces results in contamination of the teats and udders by environmental pathogens.

Overcrowding. The stress of overcrowding can cause changes in the intestinal flora. The high population densities used in intensive livestock production allow the rapid spread and replication of infectious agents. For example, if not properly managed, integrated livestock enterprises with large holdings associated with the adoption of intensive livestock production are conducive to the spread of infectious disease. These large holdings have resulted in major problems with manure disposal and storage, which poses a threat to health.

Air Quality of Buildings. The aerial environment of buildings is considered a major risk factor in the epidemiology of diseases of the respiratory tract of farm animals.

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Atmospheric ammonia, aerial dust, and microbial concentrations in the farrowing house and dust in the weaning house of swine herds can contribute to the incidence and severity of atrophic rhinitis in swine (Robertson et al, 1990).

Floor Quality. Flooring materials in farrowing pens may abrade the hooves of newborn pigs and provide a route for entry of pathogens into the foot, resulting in foot abscesses. The factors associated with foot abscesses in newborn pigs include pigs born in large litters (>10 pigs at birth) and born to sows with postpartum illnesses (Gardner and Hird, 1994). It is suggested that sows that were are ill at farrowing produce less milk. The reduced availability of milk probably increased fighting among the piglets and the time spent attempting to suck, and thus this resulted in more traumatic foot injury. This effect would be more pronounced in large litters in which competition for milk is already substantial. The increased frequency of lesions in the newborn of sick sows is consistent with the hypothesis that much of the injury to the claws results from the downward and outward movement of hindlimbs during sucking.

Bedding Quality. The number and type of bacteria in bedding are related to the microbial load on teat ends and rates of clinical mastitis in lactating dairy cows. Organic materials such as straw, corn fodder, and sawdust often contain $>10^6$ cfu/g of coliform bacteria when used as bedding. Bacteria counts also differ within organic beddings; wood products often contain the greatest number of coliform bacteria. Wood products, such as sawdust and shavings, have been found to be heavily contaminated with *Klebsiella* spp. In dairy herds using wood chips or sawdust as bedding, higher rates of clinical mastitis may occur than in herds in which other bedding materials are used (Bartlett et al, 1992). To control bacterial populations, a common practice on many farms that use wood products for bedding is to add hydrated lime to the stalls to control bacterial populations, because lime elevates the pH and reduces the moisture content of the bedding to inhibit bacterial growth. The addition of lime to sawdust before use as bedding reduced Gram-negative bacteria, coliforms, *Klebsiella* spp., and streptococci (Hogan and Smith, 1997).

Topography and Climatic Conditions. A number of environmental factors affect the spread of disease, including climate and topography. Temperature and relative humidity can permit the survival of pathogens outside the body and the activity of biological vectors. Tropical climates are conducive to the development of pathogens. For example, streptothrichosis is common in tropical climates because the high relative humidity promotes the development and maintenance of the causative organism. Interrelated with temperature and humidity is wind, which can disperse infectious agents either directly or through the dispersal of biological vectors, such as arthropods. The spread of insect-borne animal virus diseases can be influenced by several factors. Hosts may migrate, move, or be conveyed over long distances. Vectors can be carried on the wind for varying distances in search of hosts and breeding sites. For example, outbreaks of vesicular stomatitis have indicated that wind could have been responsible for carrying infection from northern Mexico to Arizona and New Mexico, and from there to Colorado and Utah and on to Wyoming, Idaho, and Montana (Sellers and Maarouf, 1990). The virus was isolated in sufficient amounts from *Simulium* sp. during the outbreak to suggest that it was possible that the fly infected with the virus could have been carried downwind to introduce disease elsewhere. The topographical features of a farm or an area can also influence the spread of airborne disease by affecting wind and air movements and the movement of infected animals. Deserts, mountains, and forests restrict the movement of domesticated animals. Water is even more restrictive, allowing islands a privileged position with respect to disease control.

Insect Vectors. The key determinants of the occurrence and epidemiology of theileriosis in parts of Africa are the distribution and abundance of the tick *Rhipicephalus appendiculatus*, which can be influenced by the climate (Lessard et al, 1990). Geographical information systems are now being developed to help improve the methods for defining the environmental parameters that influence the distribution and prevalence of tick-borne disease in Africa. The moisture index and the vegetation index are two parameters that have been shown to be important in determining the areas of suitability for the survival and development of the tick.

Commingling with Other Species. The presence of other species of animals on a farm may be a risk factor for infection. For example, the presence of deer on cattle farms may increase the risk of Johne's disease if the deer serve as a reservoir of the organism and graze on the same pasture (Cetinkaya et al, 1997). Natural infection of red deer with *M. bovis* from tuberculous possums occurs in New Zealand (Lugton et al, 1997). Observations suggest that the deer probably became infected through close inspection and investigation of the tuberculous possum. This deer-possum contact, and thus exposure to *M. bovis*, was related to the curiosity and social ranking of the red deer hinds.

Trade of Animals. Trade can also be responsible for disease spread by the movement of animals and their products. The pressure to improve the gene pool of a species of food-producing animal has increased the potential of spreading infectious agents internationally. Many diseases have been introduced into one country from another by the importation of unknown infected animals. At least 12 diseases of farm livestock were introduced into the United Kingdom between 1968 and 1979 following relaxation of importation regulations. Some of these diseases have been eradicated, but others such as enzootic leukosis, maedi-visna, and *Leptospira hardjo* infection are still present. It has been suggested that *L. hardjo* was introduced by the importation of leptospira-infected cattle that were obtained as a source of brucella-free stock. It is particularly difficult to prevent the entry and control the spread of those diseases with long incubation periods because infected animals may be imported and be present for several years before clinical disease or the infection is recognized. Enzootic bovine leukosis has a long incubation period, and the infection was present in Great Britain for about 5 to 6 years before it was recognized. Similarly, maedi-visna of sheep is caused by a slow virus, and the incubation period is several years. Scrapie in sheep is another example of the difficulty of preventing the entry of infected animals because of the long incubation period and the lack of a diagnostic test in the live animal. The introduction and expansion of free trade in livestock in Europe are of concern because of the risks of importing infected animals.

Treatment Techniques. An investigation of the risk factors for nocardial mastitis in dairy herds revealed that the use of dry cow therapy with intramammary products containing neomycin and the use of multidose vials of dry cow medications are the only predisposing factors identified as being significantly associated with nocardial mastitis (Ollis et al, 1991).

Pathogen Risk Factors

The risk factors of the pathogen or causative agent include its virulent characteristics and its reservoir of infection. In general, each causative agent causes a characteristic disease. However, virulence may vary among strains of an agent. For example, different genotypes of BVDV have been identified,

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which have antigenic and pathological differences that have practical significance (Ridpath et al, 1995). In the early 1980s mucosal disease in young cattle was invariably associated with persistent infection with a noncytopathogenic biotype of the virus, which the animal had since birth, followed by clinical disease later in postnatal life associated with a superinfection with a cytopathogenic strain of the virus. Newly identified isolates of the noncytopathogenic biotypes of BVDV in the 1990s were found to cause highly fatal disease (Deregt and Loewen, 1995).

Clinical disease caused by *H. somnus* was initially characterized by meningoencephalitis. Within the last decade clinical disease caused by the same organism is characterized by pleuropneumonia and myocarditis, which in some feedlots accounts for one of the most important causes of mortality in fall placed weaned beef calves in North America (Janzen, 1997). The change in the clinical manifestations is probably due to the changes in virulence of the organism. Some pathogens exist in more than one serotype, which is important if recovery from one infection with one serotype does not provide protective immunity against another. Mutations occur in infectious agents; these include changes in antigenic determinants, virulence, and the ability to spread in a susceptible population. Subgroups of BRSV have been identified based on antigenic differences (Schrijver et al, 1996). Certain subgroups are associated with severe respiratory disease, and these strains may circulate concurrently in the cattle population. It is important to monitor the strains that circulate in order to determine infection patterns and cross-protection of the subgroups over time. This provides vital information on the protection that can be provided after repeated infections with BRSV strains belonging to the same or different phenotypes, which might help design of vaccines. Infections in the absence of clinical disease are common in calves with rotavirus infections (Hall et al, 1993). Differences in virulence among bovine rotaviruses have been detected and have important implications for diagnosis and vaccines. Restriction endonuclease analysis of Australian bovine herpesvirus-1 isolates recovered between 1989 and 1993 revealed the emergence of a new genotype of the virus associated with severe respiratory disease (Smith et al, 1995). The ability of pathogens to spread from animal to animal may also vary from strain to strain. Also, vaccination with one serotype may not provide protection if the animal becomes infected with a different serotype of the same pathogen.

In recent years *Actinobacillus suis, Haemophilus parasuis,* and *S. suis* have emerged as important pathogens of swine, especially in high health status herds. These organisms are early colonizers and, for that reason, are difficult to control by management procedures such as segregated early weanings (MacInnes and Desrosiers, 1999). Vaccination, serodiagnostic testing, and even serotyping are complicated by the presence of multiple serotypes, cross-reactive antigens, and the absence of clear markers for virulence. To date, 35 different capsular types of *S. suis* have been described. Although it appears that some serotypes are typically more virulent than others, virulence varies not only between serotypes but also between strains of the same serotype. Clonal analysis is being used to assess the relationship between genetic groups of *S. suis* type 2 (Mwanki et al, 1994). *S. suis* type isolated from healthy and diseased pigs originated from diverse genetic backgrounds, which confirms that serotyping cannot be relied on for strain identification of the organism. Highly virulent and completely avirulent *S. suis* capsular type 2 strains do exist. Most Canadian field isolates of *S. suis* capsular type 2 tested do not produce the virulence-related proteins described for this bacterium (Gottschalk et al, 1998). The *S. suis* strains from Europe are genotypically different from those of North America. In a U.S. retrospective study, the various serotypes could not be readily separated based on antibiograms, epidemiological factors, or geographical region (Reams et al, 1993). Such information emphasizes the importance of improving the understanding of the pathogenesis and virulence factors of many pathogens so that effective management strategies including vaccination can be developed.

The factors that affect the viability of the organism in the environment may affect the prevalence of disease in herds in certain geographical regions. The prevalence of paratuberculosis-positive dairy herds in Michigan was greater (54%) than expected and was associated positively with acidic soil and increased soil iron content (Johnson-Ifearulundu and Kaneene, 1999). The addition of lime to pasture areas was associated with a herd being only 10% as likely to be paratuberculosis positive and with a 72% reduction in the number of test-positive cattle. Soil iron availability also may be an important risk factor for paratuberculosis because of its essential role as a bacterial micronutrient. *Mycobacterium paratuberculosis* may be particularly sensitive to environmental iron content because of its poor capacity for iron uptake. As an inefficient iron chelator, the organism competes less effectively with other bacterial species for sequestration of available iron when it exists in limited quantities. Thus higher soil iron content may favor survival of the organism in the environment, increasing the risk of transmission to a susceptible host.

Concurrent infections with two pathogens may result in more severe clinical disease than that caused by one pathogen alone. Cattle are susceptible to infection and disease caused by multiple pathogens, such as BRSV, BVDV, bovine herpesvirus-1, and *M. haemolytica (P. haemolytica),* and it is likely that concurrent infection exacerbates clinical respiratory tract disease. Concurrent infection with BRSV and BVDV resulted in more severe respiratory tract disease than did infection with either virus alone, which suggests a synergistic effect (Brodersen and Kelling, 1998).

Knowing the reservoir of infection or the source of the pathogen of an infectious disease can assist in formulating control procedures. One of the best examples is bovine mastitis caused by *Staphylococcus aureus,* in which the source of the organism is the infected cow. By milking infected cows last and using postmilking teat disinfectant and dry cow therapy, practitioners can help decrease existing infections and minimize the spread of the organism. In acute undifferentiated diarrhea of newborn calves, the causative pathogens originate from the dams and older calves, which spread the infection directly or indirectly to newborn calves. In some cases, semen is the reservoir of viruses, such as bovine herpes 1 (IBR-IPV), bovine leukosis virus, bluetongue, bovine virus diarrhea, and foot-and-mouth disease (Afshar and Eaglesome, 1990). The ability of viruses to withstand long-term freezing in semen with the potential for spreading disease among cattle populations internationally is a major pathogen risk factor. Semen from a bull persistently infected with the pestivirus can be a potential source of pestivirus infection for clean herds using the semen (Kirkland et al, 1994).

Molecular diagnostic and typing methods can be used to investigate the source of an organism. For example, in listeriosis of ruminants the identification of the source of the organism is often complicated because *Listeria monocytogenes* is ubiquitous. Use of advanced molecular techniques can help to identify the sources and restrict the scope of an epidemiological investigation (Wiedmann et al, 1997).

The antimicrobial susceptibility of bacterial pathogens can affect the clinical management of a disease such as bovine respiratory disease. A substantial decrease in efficacy

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of treatment, as indicated by increased mortality or numbers of animals requiring retreatment, requires the submission of laboratory samples for bacteriological culturing and antimicrobial susceptibility testing. Thus monitoring of the antimicrobial susceptibility trends of bacterial pathogens associated with many common diseases is an important aid to the veterinarian in selecting the most efficacious and cost-effective therapeutic agents. A 4-year survey of antimicrobial susceptibility trends for isolates from cattle with bovine respiratory disease in North America found some resistance to several common antimicrobials and high susceptibility to some newer antimicrobials such as ceftiofur and tilmicosin (Watts et al, 1994). Wide fluctuations in susceptibility also occur from year to year.

Risk Factor Assessment

The systematic identification and assessment of the interaction of all risk factors in a herd could be used to predict the health status of herds. Such protocols have been developed and are being validated (Buddle et al, 1997). The relative risk of a herd developing a syndrome (risk status) is calculated from the measurements of all the risk factors for that syndrome and then plotted on a risk status map. In the risk status map each risk factor is positioned according to the closeness of its relationship with other risk factors. Strongly associated risk factors are close together in the diagram; weakly associated ones are further apart. One position on the map represents the overall "risk" for that syndrome occurring in that herd. The position of the herd on the map indicates whether the herd has a low, intermediate, or high risk of developing that disease syndrome. Examination of French protocols for risk factor assessment to predict the health status of Australian pig herds found that risk factors were most accurate in predicting health status in postweaning problems (Skirrow et al, 1997). For example, a weaning weight of at least 7.9 kg and weaning age of 30 days optimized weaner pig performance (Buddle et al, 1997). Stocking densities and shed designs providing at least 3 m^3 air volume and 0.6 m^2 floor space per pig throughout the growing phase should be considered for an improved respiratory health status.

Methods of Transmission of Infectious Disease

Infectious disease is the result of the invasion of a susceptible host by a pathogen. Depending on the characteristics of the pathogen and the host, infection of a susceptible host may or may not result in clinical disease. Following infection, the pathogen may be destroyed and essentially eliminated by the immune response of the host. The pathogen may be excreted in various discharges for varying periods of time and serve as a source of new infection for other susceptible hosts. In some infectious diseases, the pathogen persists in the tissues of the host, even in the presence of antibody, for prolonged periods. It may be shed in various discharges continuously or intermittently. The spread of the pathogen from an infected host to another host, thereby causing infection in the new host, constitutes the complete life cycle or life history of the pathogen. A knowledge of the life history of an infectious agent, including the modes of transmission, is essential when formulating the most effective control procedures. The important aspects of the life history of an infection are the methods of transmission of infectious agents and the factors that influence the maintenance and transmission of the pathogen.

Transmission of infections may occur *horizontally* or *vertically*. Horizontal transmission is from one animal or group of animals to another. Vertical transmission is from one generation to another, usually from the dam to the newborn through embryonic or fetal infection (congenital) or through the milk after birth.

Horizontal transmission can occur by direct or indirect means. Direct transmission occurs when a susceptible host comes into contact with an infected host or its discharges, which provide a source of the pathogen. Examples of diseases that are spread by direct transmission include tuberculosis, Johne's disease, pneumonic pasteurellosis, rinderpest, infectious diarrheas of calves and piglets, and several of the helminth diseases. Cattle herds usually become infected with *M. paratuberculosis* through purchase of *unknown infected* animals. Severe outbreaks of respiratory disease in dairy cattle herds can occur following infection with BRSV after the introduction of purchased animals into the herd (Elvander, 1996). The existence of bovine herpesvirus-1 infection in Dutch dairy farms that had never vaccinated for the disease was directly related to purchase of cattle and to participation in cattle shows (van Schaik et al, 1998b). Indirect transmission of disease involves an intermediate vehicle, living or inanimate, which transmits the pathogen between infected and susceptible hosts. Living or animate vehicles of transmission are commonly known as vectors. Typical examples are arthropod and insect vectors, such as ticks and mosquitoes, that transmit infectious agents from infected to susceptible animals. Mechanical vectors are those that simply carry the pathogen from the infected or primary host to the noninfected or secondary host. The infectious agent does not multiply in a mechanical vector. For example, it is thought that *Moraxella bovis*, the causative agent of pinkeye, is spread between animals by the face fly. In a biological vector, the pathogen multiplies or undergoes part of its life cycle before transmission to the secondary host occurs. Inanimate vehicles of transmission, such as contaminated feed and water supplies, equipment, clothing, and sacks, are known as fomites. The bovine leukemia virus may be spread from an infected animal to an uninfected animal by rectal palpation without a change of sleeves between animals (Divers et al, 1995). The bacteria causing contagious mastitis in dairy cattle are commonly spread by milkers' hands, milking machines, and common udder washing towels. Anthrax may be spread through the contamination of feed and water supplies, including bone meal, forage grown on contaminated soil, and fertilizer. There are several examples of infectious agents being transmitted by airborne transmission. This may explain the recent introduction of porcine respiratory coronavirus into Denmark (Flori et al, 1996).

In England, tuberculosis is endemic in the badger population, and the badger is considered to be an ideal maintenance host for *Mycobacterium bovis* (Cheesman et al, 1989). Outbreaks of tuberculosis due to *M. bovis* continue to occur in cattle and primary infections in man are presumed to be from cattle or infectious cases in the country (Hardie and Watson, 1992). Direct contact between badgers and cattle is believed to be infrequent, but it is hypothesized that the contamination of pasture by the deposition of infectious material such as urine, feces, or sputum and the badgers' use of cattle facilities or the presence of moribund or dead badgers increase the risk of transmission. Various methods of controlling tuberculosis in badgers are now being explored and evaluated (Smith et al, 1997).

The transmission of infectious diseases is not as simple as described. The transmission of many of the common infectious diseases of food-producing animals is not well understood. A number of assumptions have been made about the modes of transmission. Many diseases are probably transmitted by both direct and indirect means. For example, nursing beef calves at 2 months of age affected with coccidiosis may ingest the oocysts from the fecal-contaminated skin of the dam while sucking or from contaminated ground, which may be wet and muddy in the spring of the year.

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Sources of pathogens from infected animals include feces, urine, nasal and ocular discharges, saliva, exhaled breath and sputum, milk, semen (Afshar and Eaglesome, 1990), uterine fluids and fetal tissues, blood, and tissues from live and dead animals. These sources provide the pathogens that can contaminate the environment of animals. Feed and water supplies, including pastures and natural water reservoirs, feeding utensils, manure disposal sites, air of animal barns, bedding and ground surfaces, equipment used in the handling and management of animals, and streams and rivers can act as contaminated environments. They also are the source of pathogens for intermediate and amplifier hosts that are involved in the transmission of some infectious diseases. Viruses are shed into the environment from clinically ill or carrier hosts. The viruses do not replicate outside living animals or humans, but they are maintained and transported to susceptible hosts. Population concentrations and movement, both animal and human, have been increasing steadily in the past century, enhancing transmission of respiratory and enteric viruses and compounding the difficulty of preventing environmental transmission. Studies on environmental survival factors of viruses have been most definitive for polioviruses, foot-and-mouth disease viruses, and Aujeszky's disease virus. Heat resistance studies have been reported on adenoviruses, African swine fever virus, and the Norwalk virus. Resistance to disinfectants has been studied for many viruses, including picornaviruses, papovaviruses, reoviruses, and retroviruses. Survival of viruses in and on a variety of fomites has been studied for influenza viruses, paramyxoviruses, poxviruses, and retroviruses. Some agents such as that causing bovine spongiform encephalopathy have incredible stability in the environment (Pirtle and Beran, 1991).

The ability of a pathogen to survive and to be transmitted on farm and veterinary equipment is a major factor in transmission of disease within and between herds. For example, *S. suis* is able to survive under farm conditions and can be transmitted by fomites such as manure-covered work boots and veterinary vehicles (Dee and Corey, 1993).

The means of entry of infection include ingestion, inhalation, conjunctivae, percutaneous, genitourinary, and intramammary routes and the umbilical vessels in newborn animals. All of these occur by natural means. Infection transmitted by medical or surgical techniques, such as the use of contaminated hypodermic needles or contaminated medications, is known as iatrogenic transmission.

To determine whether or not an infection in a herd will spread from a small inoculum, the investigator must compute the number of secondary cases resulting from one infectious animal. The ratio of secondary cases to originally infected animals is called the reproduction ratio and is commonly denoted by R_0. When $R_0 < 1$, the infection will not spread and the animal population is effectively protected from the infection. When the infection is established, but R_0 is reduced to <1, the infection will disappear provided that some additional, commonly satisfied assumptions are met. When $R_0 > 1$, the infection can spread. Therefore a strategy for controlling an infectious agent is effective when, and only when, the ratio for that strategy is <1 (DeJong and Diekmann, 1992). The value of R_0 for a given host population is determined by a number of different factors, including the transmissibility of the infection, the period over which an infected host is infectious, the population density of hosts, and, where appropriate, the density of vectors and the capacity of the vectors to transmit the infection. Some estimates of the reproduction ratio for a few animal pathogens and parasite are available (Woolhouse et al, 1997). (See application of this principle later under "Efficacy of Vaccines.")

Vertical transmission of infectious agents occurs from the parent to the offspring through embryonic or fetal infection (congenital) or through the milk after birth. Infections that are transmitted vertically include *Neospora caninum* in cattle (which may result in abortion, stillbirths, fetal mummification, and live full-term calves with or without clinical evidence of disease [Davidson et al, 1999; Gonzalez et al, 1999]), BVDV causing persistent infection in calves when infection occurs in the nonimmune dam between 42 and 125 days of pregnancy, and *M. paratuberculosis* causing Johne's disease in cattle with infection transmitted from the infected carrier dam to the calf early in life (Goodger et al, 1996). Removal of the calf from the immediate environment of the cow within 1 hour after birth minimizes the exposure of the calf to the organism from the feces-laden calving environment.

Prevalence of Infectious Disease

The food-animal industries and veterinarians are becoming increasingly aware of the need for valid information concerning the occurrence, trends, and economic impact of all diseases of herds of food-producing animals. The availability of such information is essential for improving the health and production management of herds. The National Animal Health Monitoring System (NAHMS) has been established in the United States to measure the incidence, prevalence, trends, and economic costs of diseases in food-producing animals on a national level. (Detailed information is available on the Internet at http://www.aphis.usda.gov.) Data for the monitoring program are collected by federal, state, and university veterinarians through monthly visits to farms, which are selected by a random sampling procedure in seven states. Dairy cattle, beef herds, beef feedlots, sheep flocks and feedlots, swine herds, and poultry flocks have been included. Similar national programs for monitoring diseases of food-producing animals have been established in Canada and in the United Kingdom. The results provide information on the incidence of infectious diseases in the herds selected at random and surveyed for the incidence and costs of all clinical diseases over 1- to 2-year periods. They are discussed in the chapters dealing with the general aspects of dairy and beef herd health management.

Routine health management programs provide the sentinel herds and general data for an ongoing disease and production surveillance system (Dohoo, 1988). As described in Chapter 1, the Animal Productivity and Health Information Network (APHIN) in Prince Edward Island consists of a number of microcomputers on farms, in veterinary and diagnostic laboratories, and in processing industries, which are linked to a central database at Atlantic Veterinary College. Health and production data from these various sources are entered into the system using microcomputers linked to the central database by long-distance telephone. The central database prepares summary reports of animal health and production of all participating herds. In addition, reports are generated for individual farms. The major advantage of this system is that it allows producers and veterinarians to see what animal health and production performance values are being achieved in the population of animals at large and to compare them with those of individual producers. Such comparisons can serve as a powerful motivating force for producers to improve the efficiency of livestock production by health management.

Economics of Infectious Disease

Livestock producers need to know the cost of diseases, especially of subclinical or insidious diseases that affect production and are usually more costly than overt clinical disease. Knowledge of the prevalence and costs of both subclinical and clinical diseases is necessary to examine the

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cost-effectiveness of changing management or initiating specific eradication or control procedures.

The costs associated with infectious diseases include losses from deaths, decreased production from clinical and subclinical diseases, time and resources necessary to make a clinical and laboratory diagnosis, drugs, time and labor required to treat animals, cost of vaccines and their administration, and cost of depopulation and repopulation if used as a technique to control or eradicate a disease. The cost of continued surveillance to prevent the entry of infected animals is also significant in the management of infectious diseases.

Traditionally, the economics of disease have been considered in two ways (McInerney, 1988). The first has been to measure the losses caused by disease and to assign monetary values to those various losses, such as suboptimal performance, treatment costs, and deaths. The second method for economic application has been assessing disease control programs using cost-benefit analysis. In recent years, much has been written about the cost-benefit approach, which attempts to show the value of different methods of treating or controlling disease. However, these traditional methods of economic analysis, although useful management techniques, are considered to be merely cost accounting and do not represent an economic analysis of disease. They do not provide any guidance in devising, selecting, implementing, and monitoring a management plan, which is required for an economic analysis of livestock disease.

A rigorous economic analysis of disease begins with the principles of economics, which consider all activity in the real world (McInerney, 1988). Economic activity is the process whereby basic resources are physically transformed into other physical goods (or services) by a process called production. The physical goods are then distributed to the people who make up the economy by the process of consumption. Thus there are two central axioms of economics: (1) economic activity is directed entirely toward the benefit of people, and value arises solely from what those people want, and (2) economic activity is governed by the resources available, and the concept of cost derives from the resources that have to be diverted from some other use (McInerney, 1988). These principles provide the basis for introducing disease as an economic concept. Disease can operate on the production system to reduce the amount (or quality) of livestock products gained from the resources and thus reduce the benefits available to the people.

Predicting and Preventing Epidemics of Infectious Disease

An epidemic is the occurrence of disease in a population at a level that is clearly in excess of its expected frequency. The ability to predict that certain circumstances, unless removed or modified, could result in an epidemic of disease in a herd would be a valuable asset in a health management program. A variety of different methods are used to forecast potential problems. During regular herd health or emergency visits, a veterinarian may recognize the presence of certain risk factors known to predispose to disease. If corrective action is recommended, it may be possible to prevent the disease or minimize its incidence. For example, the examination of a beef herd a few months before calving may reveal the presence of risk factors, which if removed or modified could minimize the incidence of acute undifferentiated calf diarrhea. A change in milking technique may result in an increased incidence of subclinical mastitis. However, sometimes the veterinarian does not learn about such changes until the incidence of disease increases. Regular monitoring of the individual SCC is a useful aid in monitoring the prevalence of infection in the herd.

It may be possible to take corrective action before a costly herd problem develops. In large beef feedlots, the use of computers to monitor the occurrence of disease in recently arrived animals can predict the possible occurrence of epidemics. Based on the rate of new cases each day (the *epidemic curve*), within a few days after arrival it is possible to predict that a certain group of animals are of high risk and can develop a high incidence of respiratory disease. Unless efforts are made to minimize the daily rate of new cases, the affected group will develop a high incidence of respiratory disease. The treatment of each animal in such a high-risk group with an antimicrobial before they become clinically affected can reduce the morbidity and case fatality rates (Harland et al, 1991). (See Chapter 5.)

A national computerized system of abattoir condemnation data from cattle, sheep, and pigs has been developed in Northern Ireland (McIlroy et al, 1990). Liver condemnations because of fascioliasis reflect the prevalence of the disease in cattle and sheep populations. When combined with meteorological data, the condemnation rates can be used to forecast the prevalence of fascioliasis for the next year accurately. Such a system would allow the formulation of control strategies based on the expected prevalence of disease in any region of the world where relevant abattoir and meteorological data are available.

For certain infectious diseases, the prevalence of infection can be monitored over time by regular laboratory examination of a small, random sample of the population. A seroepidemiological profile of the presence of several diseases of cattle can be followed indefinitely and changes in prevalence related to the seasons of the year, number of clinical cases and other factors (Rodriguez et al, 1990). Selected enteropathogens from the feces of calves can be monitored over time and the results related to season of the year and age of the calf (Hird et al, 1990). Microbiological surveillance of infection is used to detect persistent infection with BVDV in resident and newly acquired bulls in artificial insemination centers (Howard et al, 1990). The prevalence of some infectious agents that may be associated with abortion in cattle can be estimated by the serological examination of bovine fetuses from pregnant cattle in an abattoir.

The number of animals that must be sampled in a population in order to detect infection or disease depends on the prevalence of infection in the herd (DiGiacomo and Koepsell, 1986). (See Chapter 5.)

INVESTIGATION OF INFECTIOUS DISEASE IN HERDS

Recognition of an Herd Epidemic

Investigation of infectious diseases in herds is becoming a more common activity in farm animal practice. A disease may be endemic in the herd, and the veterinarian may attempt to identify infected animals as part of a control program. In other instances, the diagnosis may be obvious but the causes and risk factors may not be well understood. Epidemics and episodes of endemic disease in herds provide opportunities for the veterinarian, the veterinary researcher, and the diagnostic laboratory to obtain some useful epidemiological information about the disease. Screening tests are also used commonly to monitor the prevalence of disease in herds as is generally done in mastitis control in dairy herds. Surveillance programs to monitor the prevalence of disease are only useful if a good screening test is available and when the characteristics of the test, such as sensitivity, specificity, and predictive values, are well understood.

Veterinarians should provide comprehensive clinical and epidemiological diagnostic services when herd epidemics occur. These include working with veterinarians from the

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state and provincial diagnostic laboratories and field investigation services so that as much useful information as possible about the nature of the disease can be generated for application to future epidemics and for the control of new cases. Investigation of herd epidemics provides an opportunity for the veterinarian to establish a health management program on the farm for the control of specific diseases. Veterinarians need to become more involved with herd health management; this includes solving herd problems, giving plans of action and recommendations, and conducting subsequent follow-ups to complete the health management cycle.

Clinical Examination of the Herd

Epidemics occur sporadically and may require in-depth clinical, epidemiological, and laboratory investigations to determine the risk factors or specific causative agents. An epidemic is the occurrence of disease in a population of animals at a level clearly in excess of its expected frequency (Lessard, 1988). The term is also used to describe any sudden impairment of the productivity of a herd or group of animals that may indicate the presence of subclinical disease. A sudden, unexpected decrease in milk production or reproductive performance in a dairy herd, a decrease in weight gain in grower pigs, or a reduction in the number of piglets born per sow may indicate an outbreak of subclinical disease despite the absence of clinical signs of disease.

Herd epidemics of infectious disease occur even in well-managed herds. Whenever possible, the veterinarian should visit the herd and conduct a thorough epidemiological investigation of the epidemic, including clinical examination of affected animals. If necessary, appropriate laboratory samples should be collected from both affected and normal animals. It is difficult to determine the important risk factors for outbreaks of infectious disease without visiting the farm and conducting a clinical and epidemiological investigation. The aim is to identify risk factors and attempt to eliminate or modify them. For most of the common types of infectious disease outbreaks that occur in North America, there is little evidence that the differences in disease levels among herds can be attributed to microbiological differences among herds (Hancock and Wikse, 1988). Many of the differences in disease levels among herds can be attributed to differences in the host and environmental factors under the control of management.

The principles and methods used in the investigation of disease outbreaks in herds are presented in Chapters 2 and 5.

Clinical Management of the Epidemic and Future Control

The investigation and clinical management of herd epidemics also involves providing recommendations about appropriate treatment, such as antimicrobial therapy, and advice on the withholding of milk from lactating dairy cattle or the slaughter of animals until the withdrawal period has expired.

The veterinarian has an obligation to use every opportunity to make livestock producers aware of the principles of effective disease control. This is most effectively done on a one-on-one basis. Such information can also be presented on a group basis with regular meetings of producers, at which information on disease control is given and discussed. Livestock producers look to their veterinarian for advice, and veterinarians should respect that trust. The success of infectious disease control on the farm depends heavily on the willingness and ability of the farmer to implement the recommendations of the veterinarian, who in turn must become skilled in explaining the principles so that they are understood and can be implemented. Once the veterinarian has left the farm, control of infectious disease, as with all other diseases, is in the hands of the livestock producer.

Final Report to the Owner

In order to complete a disease outbreak investigation, the veterinarian must record detailed epidemiological and clinical data for the duration of the epidemic. The appropriate analysis and interpretation should be made, followed by a final report to the producer.

DECISION ANALYSIS IN THE CLINICAL MANAGEMENT OF INFECTIOUS DISEASE

Decision analysis can be used to assist the veterinarian in making economic decisions. Concerns about groups or herds of animals with certain infectious diseases, whether to vaccinate as part of a control program or in the face of an outbreak of disease, and whether to depopulate and repopulate when faced with a disease, can be dealt with using decision analysis. Structuring the problem into a decision tree makes the questions clearer and forces the decision maker to think through the problem systematically while considering all alternatives Often, several possible options are available as well as uncertainties or risks associated with the possible outcomes for any given potential alternative. Decision analysis techniques are presented in Chapter 2.

TREATMENT OF INFECTIOUS DISEASES OF FOOD-PRODUCING ANIMALS

Animals affected with infectious diseases caused by bacteria are usually treated with antimicrobial drugs to minimize the effects on production, to prevent deaths, and to prevent further spread of the disease by elimination of the infectious agent, if possible. Animals affected with certain viral infections, particularly of the respiratory tract, may also be treated with antimicrobials in an attempt to prevent secondary complications caused by bacterial infections. In some situations, all animals in a group may be treated prophylactically to reduce the incidence of disease. For example, the parenteral administration of an antimicrobial to all high-risk feedlot cattle on the day of arrival in the feedlot can markedly reduce the incidence of acute respiratory disease, most of which is pneumonic pasteurellosis (Harland et al, 1991).

Culture and sensitivity testing to determine the most appropriate antimicrobial for a particular bacterial infection is commonplace. The relationship among the zone of inhibition of the disk diffusion test, the minimal inhibitory concentration achieved in the animal, and the concentration of the drug at the site of the lesion is critical and makes interpretation of the test results difficult.

The use of antimicrobial drugs in food-producing animals may result in drug residues in meat and milk, which are now a major public health concern. It is the veterinarian's responsibility to educate the producer on the correct use of antimicrobials and to adhere to stated withdrawal times for each drug used. Violations of drug withdrawal requirements in dairy herds that sent culled cows to slaughter before the withdrawal period elapsed have been reported (Marteniuk et al, 1988). The positive identification of each treated animal and the keeping of appropriate records to indicate the date on which the animal was treated and with which drug have become vital components of animal health management programs. A food-animal residue avoidance databank (FARAD)

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is now available by online computer as a single source of large amounts of information on veterinary pharmaceuticals, pharmacokinetics, and physicochemical properties of drugs and other chemicals used in livestock production (Sundlof et al, 1986). Several tests are available to detect antimicrobial residues in milk; the live animal swab test (LAST) can be used for residues in urine (Korsrud and MacNeil, 1988), and tissue testing can be performed for a wide variety of drugs and chemicals. Sulfamethazine residues were found in swine carcasses because of producers' failing to observe drug withdrawal times, feed mill mixing errors, fecal drug recycling, and unintended exposure of animals to feed contaminated with the drug before marketing (Bane et al, 1989). The tests used for the detection of sulfamethazine residues in swine, however, are not considered adequate for on-farm monitoring. Mass medication of feed and water may be an option for the clinical management of certain infectious diseases affecting herds of food-producing animals. However, the practice is not reliable because of wide variations in the amount of feed and water intake by individual animals within a group affected by varying stages of infection.

The extra-label use of antimicrobials and other drugs for the treatment of infectious diseases of food-producing animals can be a cause of drug residues in meat and milk. Extra-label refers to using drugs at a dose higher than approved, or by a route not approved, for the treatment of diseases other than for those approved, in a species for which the drug is not approved, or when unapproved for any use in any species. In the United States, veterinarians are allowed to prescribe, dispense, and use drugs at extra-label indications provided they follow certain conditions, including the following:

1. A careful medical diagnosis is made by an attending veterinarian within the context of a valid veterinarian-client-patient relationship.
2. A determination is made that there is no marketed drug specifically labeled to treat the condition diagnosed, or that drug therapy at the dosage recommended by the labeling has been found clinically ineffective in the animals to be treated.
3. Procedures are instituted to ensure that the identity of the treated animals is carefully maintained.
4. A significantly extended period is assigned for drug withdrawal before marketing meat, milk, or eggs; steps are taken to ensure that the assignment timeframes are met and no illegal residues occur.

Veterinarians have a responsibility to use drugs at the proper dosage, to justify their use by an extra-label route to provide specific information regarding withholding times associated with extra-label use, and to recognize the privileges and responsibilities.

REGULATORY VETERINARY AUTHORITIES AND DISEASE CONTROL

Most provincial, state, and federal government agencies employ veterinarians whose responsibility it is to ensure that the animal disease regulations for a particular area or for the entire country are followed by livestock producers and veterinary practitioners. A major responsibility of regulatory veterinary medicine is preventing the entry into the country of foreign or exotic diseases, which are a potential threat to the native population of animals. These diseases do not normally exist in the country or, if they have occurred, have been quickly eradicated by a slaughter policy. Preventing the entry of exotic diseases such as foot-and-mouth disease in cattle, bluetongue in sheep and cattle, hog cholera, and African swine fever is a major concern of regulatory authorities in countries that are declared free of those diseases. Regulatory agencies are also responsible for another group of diseases, which may also be reportable or notifiable but are not exotic. These diseases are considered important enough to the health of the national herd or to the human population as possible zoonoses that control procedures are part of the animal disease statutes of the country. Anthrax, brucellosis, tuberculosis, rabies, scrapie, pseudorabies, and bluetongue are examples of reportable diseases in Canada. Private practitioners must report the occurrence of these diseases to the regulatory veterinarians, who investigate the incident, conduct appropriate diagnostic testing, and institute standardized control procedures.

PRINCIPLES OF CONTROL OF INFECTIOUS DISEASES

Prevention, control, and *eradication* are the three terms used most commonly in association with disease control activities. We are unaware of any precise distinguishing definition for each of these terms, and there can be considerable overlap among their meanings. However, under practical conditions, all three methods are used to varying degrees to either eliminate disease or minimize its frequency and effect on production.

Prevention can refer to excluding clinical disease or infection from an unaffected population or protecting a population from clinical disease in an infected area by vaccination or other means. Quarantine and vaccination are examples of primary prevention. Vaccination does not prevent subsequent exposure to the infectious agent but can prevent a sufficient cause from causing clinical disease by rendering the animal immune to the level of challenge by the agent under field conditions. Secondary prevention includes those activities designed to detect disease processes as early as possible and to apply treatment before clinical disease occurs.

Control describes efforts directed toward reducing the frequency of existing disease to biologically or economically justifiable levels. For most of the common infectious diseases of food-producing animals, it does not mean the complete elimination of disease, because there may be a level of disease in the population below which the cost of further expenditure on control would be greater than the benefits derived.

Eradication usually refers to eliminating specific pathogens and hence disease from a herd or a defined area. However, the term is not absolute. Compulsory eradication schemes involving the slaughter of all affected and exposed animals are used to eradicate foot-and-mouth disease when it occurs in countries that are normally free of the disease. The disease usually does not recur unless the pathogen is introduced into the population of animals. Eradication is also used when attempting to eliminate the organism that causes footrot in sheep and *Streptococcus agalactiae* as a cause of mastitis in dairy herds. In both these examples, the possibility always remains that the organisms may not be completely eliminated from a particular herd of animals or they may be reintroduced more easily than are the foreign diseases into a country.

The following sections outline the principles of eradication and control procedures that can be used in herds of food-producing animals at the population level. It must be emphasized that, with the exception of a compulsory eradication program, the control of infectious disease is generally relative rather than absolute.

Principles of Eradication

Some infectious diseases can be eradicated from a herd, geographical area, or country. Eradication means complete elimination of the causative agent from the individual, usually by treatment or by removal or disposal of the infected animal(s) from the herd, so that no additional cases occur unless intro-

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duced from the outside, and so that specific immunization or treatment procedures are no longer needed. The control of disease by eradication has been a strategy used for many years, even long before the specific causes of diseases were known. Eradication can be achieved in a number of ways.

Compulsory Destruction and Disposal of All Clinically Affected and Exposed Normal Animals in an Affected Herd

Compulsory destruction and disposal is used by regulatory veterinary authorities for the eradication of exotic or foreign diseases, such as foot-and-mouth disease in countries that have a policy of being free of the disease. All clinically affected and in-contact susceptible animals are identified, killed, and disposed of by burning or burying. It may even mean destruction of animals from an adjoining farm that may have had contact with the affected herd through the movement of personnel back and forth between farms. All affected farms are quarantined, and movement of animals in a specified area may also be prohibited. In countries with such an eradication policy, the public at large supports the policy and the public treasury usually provides the owner with financial compensation for the animals that are slaughtered. Following disposal of the herd, standardized clean-up and disinfection procedures and a period of vacancy are mandatory, followed by the use of sentinel animals to ensure that disease does not occur before repopulation of the farm with the original species of livestock.

Eradication of highly infectious diseases depends heavily on controlling animal movement. A classic example is the difficulty of controlling the spread of contagious bovine pleuropneumonia. By relatively unsophisticated methods of prohibiting cattle movement, slaughtering diseased and contact cattle, and administering crude vaccination, contagious bovine pleuropneumonia was eradicated from most parts of Western Europe by the beginning of the twentieth century, although sporadic outbreaks were continuing on the French-Spanish borders until the 1920s (Egwu et al, 1996). The disease, however, has persisted in some parts of Europe, and outbreaks have occurred recently in Portugal and Italy. It spread to South Africa from Europe into East Africa by Boer settlers who trekked their cattle to the Kenyan highlands around the turn of the century. The disease is now endemic in much of sub-Saharan Africa, and its incidence is increasing. Countries like Kenya, Uganda, Mali, Rwanda, Tanzania, and Botswana that were once free of the disease are now experiencing endemic disease. To be effective requires full cooperation from cattle owners and timely compensation payments needed to restock herds. This strategy may be impractical in developing countries with a pastoral economy. Bureaucratic problems leading to delays in paying compensation and political considerations are contributory factors in the continuing prevalence of the disease in Europe. Guidelines for the eradication of the disease from endemic regions and eventually around the world have been described and serve as a model (Egwu et al, 1996).

Identification and Disposal by Slaughter of Infected Animals From a Herd

Diagnostic tests are used to identify infected animals, which are then removed from the herd and disposed of by slaughter for salvage. Only those animals that are positive for the test are removed from the herd, and, depending on the particular disease, all remaining test-negative animals in the herd are retested at suitable intervals until all animals are negative on one or more tests. Animals found to be test positive at each test are removed and sent to slaughter. This method has been used for the eradication of diseases such as tuberculosis, brucellosis in cattle, enzootic bovine leukosis, Johne's disease, and maedi-visna in sheep. Financial compensation to the owner is commonly provided by the government for the eradication of diseases such as brucellosis, tuberculosis, and Johne's disease. The identification of infected animals depends almost entirely on diagnostic tests, which are not 100% sensitive and specific. Therefore this method, although highly successful, is not as reliable as the policy of destroying entire herds of animals for the eradication of foreign diseases.

Since Switzerland and Denmark eradicated bovine herpesvirus-1 in the last decade, attention has been focused on the eradication of the virus from the European Union. Switzerland and Denmark were able to eradicate the virus by test and removal procedures for serologically positive animals because of its low prevalence at the start of the eradication program. In countries with a high prevalence of disease, eradication is only economically feasible by the prevention of new infections combined with an increased rate of removal of infected animals. In 1998 the Netherlands began a compulsory bovine herpesvirus-1 eradication program. To make the Dutch farmers aware of their bovine herpesvirus-1 status, samples of bulk milk were taken from many dairy farms and tested for the presence of antibodies with an ELISA (Van Wuijckhuise et al, 1998).

In an individual herd, a disease caused by a specific pathogen can be eradicated by disposal of the entire herd (depopulation), followed by a period of vacancy of the buildings, and then by repopulation with animals from herds certified to be free of the infectious disease. Animals that are imported into a herd or into a country may be quarantined for a certain time and tested for the presence of infection before they are introduced into the herd. Pneumonia in pigs caused by *Actinobacillus pleuropneumoniae* and *M. hyopneumoniae* can be eradicated using this procedure.

When certain diseases caused by specific pathogens have been eradicated from a herd, the herd can be closed. In this case, no further live animals are introduced, which prevents the entry of unknown infected animals. Genetic improvement in the herd is achieved through artificial insemination, embryo transfer, and selection within the herd.

For some diseases, a combination of control procedures followed by eradication are used. For example, the prevalence of brucellosis in Canada was reduced by calfhood vaccination and serologic testing of herds to detect infected animals, which were removed and sent to slaughter. Vaccination prevented abortion and, although infection was still possible, the prevalence declined. When the prevalence was low, the vaccination of calves was deemphasized, serologic testing continued to detect and remove positively infected animals, and eventually eradication was achieved. A simulation model of different control strategies for ovine paratuberculosis found that vaccination of the replacement ewes was the most cost-effective strategy compared with testing and culling, vaccination and culling, and no intervention (Juste and Casal, 1993). Eradication of the disease can occur within 10 years even with a vaccine efficacy of only 30%.

Elimination of Infection by Treatment

Elimination of infection involves the treatment of infected animals that have been identified by clinical examination or diagnostic tests. Examples include the use of antibiotics for the treatment of sheep with footrot, cattle with leptospirosis, and cattle with mastitis caused by *S. agalactiae*.

Following eradication of the infection from a herd, area, or country, constant surveillance to prevent the entry of unknown infected animals into the area or the herd is necessary. For the notifiable diseases of the country, this requires a regulatory system that certifies that exported and imported

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animals are free of certain infectious agents. For the individual livestock producer who wants to purchase breeding stock, it requires an effective testing and certification system that certifies that the purchased animals are free of the disease and that they originate from a herd that has been free of the disease for a specified period.

Principles of Control

The inability to eradicate many infectious diseases totally leaves control or "living with the disease" as the most common alternative. The ideal objectives of control are to reduce both the prevalence of existing infections and the incidence of new infections as well as the morbidity and mortality rates from clinical disease. For example, staphylococcal mastitis of dairy cattle cannot be eradicated. However, the adoption of a reliable mastitis control program can reduce both the prevalence of existing infection and the incidence of new infections and clinical cases of mastitis. Similarly, acute undifferentiated diarrhea of newborn calves cannot be eradicated. Some calves always develop the disease, but the incidence of clinical disease can be reduced using the principles of control. These methods include the reduction of infection pressure, adequate colostrum, and the use of vaccines in the pregnant cow. The principles of control include the following.

Reduce Infection Pressure and Prevent New Infections

One of the most important principles of infectious disease control is to minimize the infection pressure on noninfected susceptible animals and to prevent new infections. This means the maintenance of a clean environment so that contamination of the feed and water supplies, bedding, and other materials with infectious agents is minimized. Dairy cows housed in a dirty environment may experience a high incidence of coliform mastitis caused by environmental pathogens. The prevalence of subclinical mastitis in dairy cattle caused by *S. agalactiae* and *S. aureus* are related to the infection rate in the herd and to the levels of sanitation and hygiene practiced during milking. In the ideal situation, infected animals that are known sources of the pathogens would be kept separate from susceptible animals. However, in herds of animals, this is often unrealistic. For example, in the case of the infectious enteric diseases of newborn beef calves, the dams are the source of the pathogens and separation of the calves from the dams is not practical. In such cases, control depends on the achievement of adequate colostral immunity and minimization of infection pressure when the calf is most susceptible. The environment of the animals must not be allowed to become heavily contaminated with pathogens shed by carrier animals. Calving grounds in beef herds can become heavily contaminated with enteropathogens because of the buildup of feces, which increases the risk of diarrhea in newborn calves. The control of *Cryptosporidium parvum* infection in calves is dependent on reducing the infection pressure with good management practices and attention to hygiene when handling infected calves (Harp and Goff, 1998). In groups of animals, high population densities or crowding must be avoided to control the spread of infection among animals. Feed and water supplies must be handled and situated to avoid fecal contamination. On the other hand, a controlled infection pressure may be useful. Low levels of contamination below those that result in clinical disease can result in effective immunization, as occurs in coccidiosis. In the case of respiratory disease in feedlot cattle, infection pressure may be controlled by minimizing the mixing of cattle from different sources. This is usually not practical in custom feedlots, however, in which cattle from many different backgrounds are assembled into pens.

An example of reducing infection pressure and preventing new infections in herds is nursery depopulation for the control of porcine reproductive and respiratory syndrome in swine herds. Control within a breeding herd is based on the observation that pigs commonly seroconvert to the virus during the nursery period. Pigs are seronegative shortly after weaning, but 80% to 100% are seropositive at 8 to 10 weeks of age (Dee et al, 1997). A control program based on a *nursery depopulation* consists of emptying the nurseries and moving *all of the pigs* to off-site finishing facilities or selling them as feeder pigs. This is combined with batch farrowing and weaning at intervals of at least 3 weeks. The nurseries are completely emptied and cleaned three times with hot water and disinfectant, the slurry pits are pumped out after each cleaning, and the facilities are kept empty for 14 days, during which time all pigs weaned are moved to off-site nurseries. After this the conventional flow of pigs into the cleaned facilities is resumed. The control program can cause significant improvements in both average daily gain and percentage mortality, but it will not eliminate the virus from the herd. Using a partial budget model to measure the profitability of nursery depopulation, the financial consequences indicate that it is profitable strategy to improve pig performance in herds affected with the virus. Additional income is generated by the increased number and weight of marketable pigs, as a result of their increased growth rate and decreased mortality. Lower treatment costs reduce overall expenses, but there are additional costs because of extra feed necessary to raise the additional pigs and the costs required to house the depopulated pigs. However, it is possible that the economical benefits are due to the control of other pathogens and not merely the porcine reproductive and respiratory syndrome virus.

The details for a nursery depopulation and clean-up protocol for the elimination of the virus are shown in Table 4-3 (Dee et al, 1997).

Management of Gilt Pool. Management of the gilt pool is the single most important strategy for long-term effective control. Controlling the infection in the breeding herd is a

TABLE 4-3

Nursery Depopulation and Clean-Up Protocol for the Elimination of the Virus

Day	Procedure
1	Empty all nurseries, off-site weaning, pump out slurry pits, clean and wash rooms with hot water (>95° C) and disinfect with formaldehyde-based product. Allow disinfectant water to remain in pits overnight.
2	Pump out pits, repeat washing procedure, and disinfect in phenol-based product. Allow disinfectant to remain in pits.
3-11	Allow facility to remain vacant.
12	Pump out slurry pits, repeat washing procedure, and disinfect with formaldehyde-based product.
13	Allow facility to remain vacant.
14	Resume conventional flow of pigs into clean nurseries.

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prerequisite to controlling infection in the nursery and finishing pig groups. Strategies like partial depopulation and piglet vaccination are ineffective unless the breeding herd is first stabilized, which prevents piglets from being infected before weaning. Replacements are a major source of introduction of the virus and activating existing virus in the breeding herd. They also initiate the formation and maintenance of breeding herd replacements.

Subpopulations are subsets of naive or recently infected gilts or sows that coexist within chronically infected herds. These subpopulations perpetuate viral transmission in the breeding herd and farrowing units that ultimately produce successions of infected piglets before weaning. Modifications in gilt management that may minimize subpopulations include ceasing introduction of replacement animals for a 4-month period, beginning selection of replacements from the finishing unit, or introducing a 4-month allotment of gilts at one time.

Exposure to the virus in the breeding herd can be controlled by managing the gilt pool using two strategies. In one strategy, herds may be closed to outside replacements and replacement males and females are raised on the farm. In the other strategy, replacement gilts are held in an off-site holding facility from 9 to 12 weeks of age until breeding age at 7 to 7.5 months or even much earlier. This is combined with nursery depopulation as described previously. Before entry of the gilts into the herd they are serologically tested for evidence of seronegativity or a declining titer, which is required for entry into the herd. The gilts are isolated and quarantined for acclimatization for 45 to 60 days. This may be combined with vaccination twice, 30 days apart, after entering quarantine (Dee et al, 1998). This method reduces the risk of introducing potentially viremic animals into the existing population. The method selected depends on the production system, management capabilities, and facilities available on each farm. The introduction of younger gilts, in larger groups and less frequently throughout the year, is being recognized as the most effective method for introducing replacement stock to virus infected herds and long-term control of the disease.

Controlled Infection of Breeding Herd. The presence of subpopulations of highly susceptible breeding animals in the herd can be a major risk factor for maintaining viral transmission within problem herds and may explain recurrent outbreaks of reproductive failure. By intentionally exposing all members of a population to the virus, it may be possible to eliminate subpopulations and produce consistent herd immunity. In endemic herds, exposure of gilts to the virus before breeding is critical for prevention of reproductive failure. Seronegative replacement gilts can be introduced into seropositive herds at 3 to 4 months of age to allow for viral exposure before breeding. If the status is uncertain, quarantine and exposure to nursery pigs of the importing unit is a suitable policy if replacement gilts are brought in before they are bred.

Biosecurity. Biosecurity is any practice or system that prevents the spread of infectious agents from infected animals to susceptible animals or that prevents the introduction of infected animals into a herd, region, or country in which the infection has not yet occurred. Biosecurity, an integral part of any successful livestock enterprise, reduces the risks and consequences of introducing an infectious disease. The components of biosecurity, which include management and placement programs, farm layout, decontamination, pest control, and immunization, directly affect productivity and profitability.

For some diseases it is desirable to prevent the spread of infectious agents from a certain age group of animals to younger age groups, such as attempting to control the spread of the virus causing porcine reproductive and respiratory syndrome in pigs by depopulation of the nursery pens.

The introduction of new infections into herds can be prevented or minimized by purchasing animals directly from herds that are known to be free of a particular disease. The adoption of this principle requires awareness of the possibility of purchasing unknown infected animals and testing animals for the infection before entry into the herd. It may also require keeping the introduced animal in quarantine for several weeks after arrival before it is mixed with the other animals.

New infections can be prevented within herds or flocks by separation of the neonates from their dams immediately after birth and by rearing them in isolation from infected animals. This procedure for lambs, along with the culling of seropositive sheep, has been used for the control of ovine progressive pneumonia (Cutlip and Lehmkul, 1986). Many dairy producers now remove the calf from the dam immediately after birth and feed it colostrum rather than allowing it to remain with the cow for 3 days, as was the practice for many years. The rationale is that the calf will not become infected with the enteropathogens shed by the cow, but this has not yet been substantiated.

Caprine arthritis-encephalitis in goat herds can be controlled by removing the kids from infected herds at birth, avoiding any contact with the dam, and feeding cow's colostrum and milk (Nord et al, 1999). Seronegative groups are gradually established within each herd. When housed indoors the seronegative groups are kept segregated from the seropositive groups by compact pen fences. Total segregation of seronegative and seropositive groups, even at pasture, is of vital importance for the establishment of herds free from caprine arthritis-encephalitis virus infection. However, even with a strict control scheme, considerable reduction in prevalence of virus-positive animals rather than complete eradication is probably the most realistic aim for the first 2 or 3 years. To be declared free of the infection, a previously infected herd should test negative on at least three or four occasions at intervals of 6 to 12 months.

At least five categories of biosecurity in dairy herds have been described (Rauff et al, 1996):

Category 1: The highest biosecurity, in which replacement cattle were not purchased and animals were not taken to cattle shows or fairs.

Category 2: Herds in which producers did not purchase replacement cattle but did take their animals to shows and fairs.

Category 3: Herds in which producers purchased replacement cattle but isolated them on arrival to their farm.

Category 4: These are considered the riskiest herds, in which producers purchased replacement cattle and did not isolate them on arrival.

Category 5: Herds whose producers did not have sufficient information necessary to be classified.

Surveys of dairy herds in the United States indicate that about 50% of herds purchase replacement cattle but only 12% of those herds isolate them on arrival (Rauff et al, 1996). Most of the herds were biosecurity Category 1 (45.5%) or Category 4 (40%). Only 11% of dairy herds exhibited cattle from their herds at shows or fairs. Veterinarians need to work with their clients to develop a specific disease control and biosecurity protocol for each farm. The benefits of a rigidly enforced biosecurity program need to be stressed. Veterinarians can assist producers in developing methods to handle livestock and to purchase replacement stock by designing protocols that concentrate on general and specific aspects, such as design and construction of isolation rates.

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A closed system to prevent the introduction of infectious diseases into dairy farms is technically possible and is economical (van Schaik et al, 1998a). A closed dairy herd system could prevent the introduction of bovine herpesvirus-1, BVDV, leptospirosis, paratuberculosis, and salmonellosis and can be a good starting point for eradication of these infectious diseases from the herd. Limited field studies have found that closed dairy farms had a higher birth rate per 100 dairy cows, a lower average age at first calving, and lower costs for veterinary services (van Schaik et al, 1998b).

Biosecurity measures to prevent the introduction of infectious agents into herds is most advanced in the swine industry, where workers, visitors, veterinarians, and other service-oriented personnel may have to remove all of their street clothing, take a shower, and use clothing provided by the swine enterprise before they are allowed to enter the premises. In such high-security swine herds, no replacement breeding stock are purchased and all new gene pools may be introduced through artificial insemination.

The major routes through which an infectious agent can be introduced on to a farm follow:

1. Contact with other animals of the same species (e.g., purchased replacement stock)
2. Contact with other animal species that are potential carriers of the disease (e.g., sheep, goats, rats, and dogs in contact with cattle)
3. Transmission by humans (e.g., visitors, veterinarians)
4. Transmission by machinery (e.g., cattle trucks, manure spreaders, other tools)
5. Transmission by feedstuffs or water supplies (e.g., ditch water)
6. Transmission by air

Quarantine. A quarantine is a place or fixed period of isolation or restriction of the movement of animals. Animals being introduced into a herd or a country from another source herd or country may be quarantined in an isolation facility for a specified period during which the animals are monitored clinically or by laboratory testing for evidence of infectious disease. The objective is to ensure that the imported animals are not infected with infectious agents that could be transmitted potentially to animals of the importing herd or country. After a specified period of time, and if there is no evidence of infectious disease, the restrictions on the quarantined animals are lifted and the animals are allowed to mix with the importing herd or the general population. During the period of quarantine, transmission of infectious agents from the quarantined animals to the importing herd must be prevented by ensuring that feed and water supplies and personnel are kept separate from the nonquarantined animals. During outbreaks of highly contagious diseases such as foot-and-mouth disease, the affected farms may be quarantined for a fixed period during which animals from those farms cannot be moved to any other place, and unaffected farms may not be allowed to import animals until expiry of the quarantine measures.

Control of Wildlife Vectors. The control of some infectious diseases of food-producing animals, especially cattle, depends on control of disease in wildlife vectors that are reservoirs of infection for cattle. Tuberculosis in cattle is a significant problem in the United Kingdom because of the reservoir of *M. bovis* infection in badgers (Newell and Hewinson, 1995), and in New Zealand because of the reservoir of infection in the Australian brushtail possum (O'Neil and Pharo, 1995). In New Zealand the problem is confined to discrete areas, and spread is usually within those areas. The control scheme consists of measures to identify infected herds, to define the size of the problem, to contain the problem, and to eradicate the disease from vectors, cattle, and deer in most areas. The central cause of persistent disease nationally remains the possum, although other species may play a subsidiary role locally (Morris and Pfeiffer, 1995). The epidemiological characteristics of tuberculosis in cattle and the possums are now understood, and control strategies are based on reducing the prevalence in endemically infected possum populations and reducing the outward spread because of dispersal of pseudovertically infected juvenile possums. The use of badger vaccines in the United Kingdom is being explored as a method of control (Newell and Hewinson, 1995).

Reduction of Effects of Environmental and Host Risk Factors

A second major principle in the control of infectious disease is to reduce the effects of environmental and host risk factors that make animals susceptible to disease. Some common environmental risk factors include inadequate housing and ventilation of housed animals, rapid changes in weather, and sudden exposure to cold and windy weather. It is often difficult for even excellent livestock producers to manage uncontrollable environmental factors. In the continuing quest for more effective vaccines for the control of bovine respiratory disease, the importance of good management, housing, and husbandry must not be overlooked (Bryson, 1997). The host risk factors include failure of colostral transfer in the newborn animal, inadequate nutrition, deficiencies of trace minerals such as selenium and copper, genetic susceptibility, total lack of immunity because of no previous exposure to the antigen (either by natural infection or vaccination), age of animal (the young are more susceptible), animals that are stressed following prolonged, uncomfortable transportation, feed deprivation, immunosuppression, vaccination with live vaccines when animals are stressed, concurrent infections, and mixing animals of different ages and from different sources (as occurs commonly in commercial feedlots).

Chemoprophylaxis to Eliminate or Control Infection

The elimination of infection by chemotherapy or culling from the herd can reduce the prevalence of infection in the herd. One of the best examples of the successful application of this principle is the use of antibiotics for the control of bovine mastitis caused by the major contagious pathogens. The use of penicillin is highly effective for the treatment of cows infected with *S. agalactiae* during lactation. For cows infected with *S. aureus*, the use of long-acting penicillin at the end of lactation (dry cow therapy) is relatively effective. In both cases the use of antibiotics eliminates existing infections, and the dry cow therapy prevents new infections during the early part of the dry period. In a successful mastitis control program, both the prevalence of infections and the incidence of new infections decrease.

Metaphylaxis. Metaphylaxis is the mass medication of individual animals with an antimicrobial at a strategic time in order to prevent the onset of clinical disease. Antimicrobials are used for the control of pneumonic pasteurellosis, particularly in cattle that have just been introduced into a feedlot. The early onset of pneumonic pasteurellosis in cattle within a few days after arrival in the feedlot requires consideration of mass medication of all animals in a group as part of a health management program. Field trials indicate that administration of antimicrobials to calves at varying times on arrival in the feedlot can reduce subsequent morbidity and mortality from respiratory disease. The administration of antimicrobials to high-risk calves immediately after arrival is particularly effective under commercial feedlot conditions. Meta-

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analysis of the literature on mass medication for bovine respiratory disease indicates that prophylactic parenteral mass medication of calves with long-acting oxytetracycline or tilmicosin on arrival at the feedlot reduces bovine respiratory disease morbidity rates (Van Donkersgoed, 1992).

The injection of trimethoprim-sulfadoxine or oxytetracyclines on arrival can reduce morbidity and mortality from respiratory disease in high-risk calves. The administration of a long-acting preparation of oxytetracycline at a dose rate of 20 mg/kg BW IM to feedlot cattle on arrival can reduce the morbidity and mortality from respiratory disease. Both the IM and SC administration of oxytetracycline formulation are comparable to the IM administration of currently available oxytetracycline formulations after arrival in the feedlot. Tilmicosin, at 10 mg/kg BW SC given to calves immediately after arrival, significantly reduced the treatment rate for bovine respiratory disease during the first 5 days as well as during the first month of the feeding period (Vogel et al, 1998). The administration of tilmicosin to calves, either on arrival at the feedlot or 3 days later, reduced the treatment rate for respiratory disease in the first 30 days. The average daily gain was also improved in the treated group compared with the controls, and the feed conversion efficiency over the first 60 days of the feeding period was superior in the medicated group compared with the nonmedicated animals.

Mass Medication of Feed and Water Supplies. Medication of the feed and water supplies has given variable results because of the difficulties in obtaining adequate levels of antimicrobials in those cattle that most need them. In normal weaned beef calves at 6 to 8 months of age, blood levels of sulfamethazine of 5 mg/dl or greater can be achieved in 15 to 24 hours by providing medicated water at a dose rate of approximately 150 mg/kg BW. At 75 mg/kg BW the same blood levels are achieved by 72 to 84 hours. A standard recommendation is to provide 150 mg/kg BW for the first 24 hours and reduce the level to 75 mg/kg BW for the duration of the medication period, which may last from 5 to 10 days. A feed additive containing 700 mg/head/day of chlortetracycline and sulfamethazine from the day of arrival at the feedlot to day 56 of the feeding period improved average daily gain and feed conversion and reduced the incidence of bovine respiratory disease for days 0 to 28 and 0 to 56, the rate of relapses and mortality for days 0 to 56, and the incidence of chronic respiratory disease for days 0 to 28 and 0 to 56. Performance and health improvements attributed to the feed additive were cost-effective. However, medication of the feed and water supplies can result in a false sense of security, and the number of advanced cases of disease can actually increase.

Interferon Medication. Interferons are a heterogeneous family of cytokines that have antiviral, immunomodulatory, and cell growth inhibitory activities (Moore, 1996). Interferons are efficacious therapeutic agents for the treatment of several clinically important infectious diseases of food animals. None of the interferons is approved for use in food-producing animals.

Enhancement of Immunity Using Vaccination Programs. Vaccination is exposing an animal to an antigen derived from an infectious agent so that an immune response is stimulated and acquired resistance to that infectious agent is achieved before natural infection occurs. Several criteria must be considered to determine whether vaccination is either possible or desirable in controlling a specific disease (Tizard, 1996). The first is the absolute identification of the causal agent. Second, it must be established that an immune response actually can protect against the disease in question. Third, before using a vaccine, there must be assurance that the risks of vaccination do not exceed those associated with the chance of developing the disease in question. Thus the decision to use vaccines for the control of any disease must be based on considerations not only of the severity of the problem, but also of the prospects for its control by other techniques, such as removing or reducing the effects of risk factors.

When vaccines are used to control disease in a population of animals rather than in individuals, the concept of herd immunity should also be considered. Herd immunity is the resistance of an entire group of animals to disease conferred by presence in the group of a proportion of immune animals. Herd immunity presumably acts by reducing the probability of a susceptible animal meeting an infected one so that the spread of disease is slowed or terminated. If it is economically acceptable to lose individual animals from disease while preventing epidemics, it may be possible to do so by selective vaccination of only a proportion of the herd (Tizard, 1996).

Animals may be rendered immune to an infectious disease by *passive* or *active immunization* (Tizard, 1996). Passive immunization provides temporary resistance by transferring antibodies from an animal that possesses them from a natural infection or vaccination to an animal that does not. The transfer of colostral immunoglobulins is an example. Passive antibodies provide immediate protection that is short-lived because the antibodies are catabolized. The control of acute diarrhea in newborn calves can be aided by vaccination of the dam in pregnancy with vaccines containing antigens of *E. coli* 0157:H7, rotavirus, and coronavirus. The pregnant animal develops an immune response to these antigens and produces antibodies that are concentrated in the colostrum and subsequently transferred to the calf. Active immunization is the result of natural infection or vaccination, which involves the administration of an antigen to an animal so that it responds by developing a protective immune response that may be antibody-mediated, cell-mediated, or both. Reimmunization or exposure to infection results in a secondary immune response. Protection is not conferred immediately but usually requires several days or a few weeks; however, once established, it is long lasting and capable of restimulation.

The ideal vaccine should confer prolonged immunity to both the animal vaccinated and its fetus. It should be free of adverse side effects. It should be inexpensive, stable, adaptable to mass vaccination, and, ideally, should stimulate a response distinguishable from that resulting from natural infection so that vaccination and eradication may proceed simultaneously.

The classic vaccines can be divided into two groups according to the status of the organism or bioactive agent included as the antigen: live or killed (inactivated). The term "killed" is used when bacterial vaccines are discussed, whereas the term "inactivated" is used for vaccines used against viruses or toxins.

There are relative advantages and disadvantages of live and killed vaccines (Table 4-4) (Tizard, 1990). Two of the prerequisites of an ideal vaccine—high antigenicity and the absence of adverse side effects—tend to be mutually incompatible. Vaccines containing viable infectious agents stimulate the best immune response but have the potential to produce disease because of residual virulence, whereas the antigens in killed vaccines may be relatively poor immunogens but are usually much safer.

Live Vaccines. The advantages of live vaccines include the following: strong and long-lasting immunity, few inoculating doses required, administration possible by nonparenteral routes (e.g., intranasal), adjuvants unnecessary, less chance of hypersensitivity, and viral vaccines may stimulate interferon production.

The disadvantages of live vaccines include the following: systemic reactions because a mild form of the disease may occur, possibility of reversion to the virulent state by muta-

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TABLE 4-4

Advantages and Disadvantages of Live and Killed (Inactivated) Vaccines

	Live Vaccine	Killed (Inactivated) Vaccine
Advantages	Strong and long-lasting immunity; few inoculating doses required; effective by nonparenteral routes (intranasal, oral); less chance of hypersensitivity; may stimulate interferon	Unlikely to cause disease; stable on storage
Disadvantages	Systemic reactions caused by mild form of disease may occur; possibility of reversion to virulent state by mutation or recombination of a piece of genome with a mild strain of the pathogen; possibility of perpetuation of the vaccine antigen in the animal or environment; may cause abortion; limited shelf-life, requires defined temperatures for storage; possibility of contamination with adventitious agents	Possibility of incomplete inactivation; generally induces short-lived immunity; effective only by parenteral route, multiple doses may be required, which increases cost; hypersensitivity may occur because of antigenic modification; use of adjuvants in vaccines may cause local reactions at site of vaccination

tion or recombination of a piece of a genome with a wild strain of the pathogen, possibility of perpetuation of the pathogen in the animal or its environment, possibility of abortion in pregnant animals, limited shelf life, requirement of a defined temperature for storage, requirement of a biological system for vaccine production, and possibility of contamination with adventitious agents. However, the proper use of modified live virus vaccines does not have *immunosuppressive* consequences in healthy animals in which there is usually a significant antibody response to the administered antigen. Vaccination of healthy cattle with a modified-live BRSV vaccine does not result in adverse clinical reactions, leukopenia, alteration in blood leukocyte subsets, and decrease in phytomitogen-induced lymphocyte blastogenic responses (Ellis et al, 1990).

Killed Vaccines. The advantages of killed vaccines are that they are unlikely to cause disease because of residual virulence or reversion, and they are stable on storage.

The disadvantages of killed vaccines include the following: possibility of incomplete inactivation exists; they generally induce short-lived immunity; they must be given parenterally; generally a high antigenic mass is needed and therefore multiple doses are required, which increases cost; and they are often associated with an undesirable immune response such as hypersensitivity because of antigenic modification or contamination. Also, the use of adjuvants to increase effective antigenicity can cause severe local reactions that develop into small granulomas. These lesions can be unsightly and cause concern about condemnations at the time of slaughter.

The disadvantages of the conventional vaccines have created the need to develop vaccines based on a solid knowledge of elementary surface antigenic structures (epitopes or antigenic determinants) related to protection and immunopathology. This has led to an interest in developing second-generation vaccines. These new vaccines are characterized by the use of techniques involving recombinant DNA, monoclonal antibodies, and protein engineering (chemical synthesis of protein antigens). These techniques are commonly referred to as biotechnology.

Biosynthetic Vaccine. A biosynthetic vaccine is a formulation containing a noninfectious, protective subunit immunogen that is produced in or by a biological system. Isolated structural components of infectious pathogens, particularly proteins, are immunogenic and provoke protective immune responses with fewer undesirable side effects generally associated with whole-agent vaccines. A subunit vaccine that contains only those immunogenic components necessary to elicit a protective response and excluding others unnecessary for immunity has several attractive features. First, and of major importance, is safety; subunit vaccines lack infectious material, and no infection, either acute, persistent, or latent, can be established in vaccinated animals. This characteristic reduces complications arising from vaccination of immunocompromised or pregnant animals. Second, adventitious agents can be eliminated, thus preventing complications such as allergic reactions and immunosuppression from extraneous agents. Third, subunit vaccines are stable, allowing for wide distribution and prolonged storage. Another advantage of subunit vaccines is that vaccinated animals can be distinguished serologically from infected animals, which is a major advantage in disease control and eradication programs. The disadvantages of subunit vaccines at the present time include their high cost associated with research and development and the need to administer multiple vaccinations before protective immunity is established. Immunostimulants such as adjuvants are usually incorporated into subunit vaccines to improve efficacy.

Recombinant DNA technology is being used to produce live, genetically engineered vaccines, such as the vaccinia-vectored vaccines. Vaccinia virus was one of the first viruses into which foreign antigens were inserted and shown to be capable of inducing immunity to the foreign antigen (Babiuk et al, 1990). Such technology has the potential to improve the efficacy of vaccines for infectious diseases and improve animal production.

Efficacy of Vaccines

The veterinary practitioner is often asked for advice about the use of vaccines for the control of infectious diseases of food-producing animals. There is probably more controversy and uncertainty about the efficacy of these vaccines than about almost any other topic in livestock production. Livestock producers are exposed to a wide variety of advertising from biological manufacturers who claim that their vaccines can provide protection against clinical disease. The producer expects the veterinarian to be knowledgeable regarding the use and efficacy of specific vaccines but is generally unaware that reliable data

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showing efficacy against naturally occurring disease may not be available to the veterinarian or are nonexistent. Producers usually assume that licensure of the vaccine is synonymous with vaccine efficacy. All of this places the veterinarian in a difficult position; the veterinarian is asked to prescribe and dispense vaccines for which there are no valid efficacy data.

The Canadian Animal Health Institute's *Canadian Compendium of Veterinary Pharmaceuticals: Biologicals and Specialties* (ed 6, 1999) lists more than 40 vaccines for the control of bovine respiratory disease and more than 10 vaccines for the control of acute diarrhea in calves. How is the veterinarian, or the livestock producer, supposed to select the most effective and economical vaccine(s) from this list of products, for which efficacy data are scant or not available? On what basis should the veterinarian select a vaccine from these lists? It should be based on a combination of efficacy, potency, safety, and cost. However, although they may be safe and relatively inexpensive, there is widespread concern among veterinarians that some of these vaccines are not efficacious. There is also a need to ensure safety of biologicals used in veterinary medicine (Evermann, 1996). Contamination of vaccines with viruses may occur, and sensitive detection systems must be applied to ensure quality control.

Field observations by veterinarians and critical reviews of the literature (Perino and Hunsaker, 1997) have suggested that the vaccines that appear to lack efficacy are those intended for the control of enteric and respiratory disease complexes of cattle. It appears that, for certain diseases, not all currently available vaccines are effective. For other diseases, there are wide differences in effectiveness among vaccines produced by different companies. In other cases, there may be considerable difference in effectiveness among serial lots of the same product. A review of the literature of the field efficacy of vaccines intended for the control of bovine respiratory disease published from 1972 to 1996 found 521 articles, and 183 were deemed relevant to the objective. Only 22 articles were considered to be of acceptable experimental design (Perino and Hunsaker, 1997). Most efficacy studies are based on extrapolation from experimental challenge experiments rather than on randomized clinical field trials under naturally occurring conditions (Higgins, 1997). Hemophilosis in feedlot cattle in western Canada is considered to be the most significant cause of mortality in fall-placed weaned beef calves despite routine single immunization of calves with a commercial *H. somnus* bacterin on arrival (Van Donkersgoed et al, 1990a). A field evaluation of the efficacy of two vaccines against pneumonic pasteurellosis in sheep being shipped from New Zealand to Saudi Arabia found no clear evidence of either vaccine resulting in a lower incidence of deaths or lesions because of pneumonia (Black and Duganzich, 1995). The vaccines are effective in the laboratory, but they are ineffective under naturally occurring conditions or the results are conflicting. Conversely, the vaccination of cows and heifers with a BRSV vaccine before parturition may unexpectedly increase milk production and first insemination conception rates (Ferguson et al, 1997). In first parity cows, vaccination had a beneficial effect on milk production during the first 14 weeks of lactation, indicating that there was a reduction in subclinical illness and an increase in dry matter intake in these cows, compared with herd mates. Second parity cows vaccinated against BRSV before calving had improved first insemination conception rates.

In some cases the vaccine may be ineffective because the antigens used in the manufacture of the vaccine may not provide optimal protection against even closely related field strains of the organisms. For example, a pentavalent leptospiral vaccine containing *Leptospira interrogans* serovar *hardjo-prajitno* did not provide protection against experimental challenge with *L. hardjo-bovis* serovars (Bolin et al, 1989). Renal carriers, with periodic urinary shedding of the organisms, were established in vaccinated and control animals after they were challenge exposed. Fetal infection, stillbirths, and birth of weak calves also occurred in both vaccinated and control cows.

The efficacy of vaccines for farm livestock has been an issue. It has been suggested that the problem of inadequate vaccine efficacy is a result of the following: (1) the reliance of the licensing agency on efficacy data generated by the manufacturer (who has a vested interest in the data), (2) the acceptance by the licensing agency of efficacy data from studies that were inadequately designed or did not provide results that could be correlated significantly with protection against the naturally occurring disease, (3) the lack of influence of data from independent laboratories, which are contrary to data on which licensure is based, (4) inadequate monitoring of the efficacy of vaccines after licensure, and (5) the unavailability of efficacy data used in licensure for peer review. Furthermore, the lack of awareness of livestock producers and veterinarians concerning the current limitation of the licensing authority further contributes to the seriousness of the problem.

The problems related to the efficacy of vaccines used in farm livestock need to be addressed by all individuals and agencies concerned with veterinary medicine. Veterinary practitioners, vaccine manufacturers, governmental agencies, diagnostic laboratories, veterinary colleges, and vaccine users all have a stake in ensuring that vaccines are safe and effective.

In Canada, it is generally assumed that the biologics licensed by the Animal Health Division, Food Production and Inspection Branch, Agriculture Canada, are safe and can stimulate protection against naturally occurring diseases in vaccinated animals (Alexander, 1989). However, there is considerable field experience suggesting that some vaccines are not effective. Outbreaks of acute respiratory disease occur in cattle that have been vaccinated with a variety of respiratory disease vaccines. When these outbreaks occur, it is difficult to document that the vaccine was ineffective for a number of reasons. It is often difficult to obtain a definitive, causative diagnosis for the reasons described earlier. It is difficult, if not impossible, to determine whether the vaccine was used as prescribed, the vaccine was stored properly and maintained its potency, and risk factors were present that overwhelmed the immune response.

What is the definition of vaccine efficacy? Efficacy could mean prevention of the disease in question or control at an economic level. It could also mean that it is economical to use the vaccine, because vaccinated animals may be more profitable than unvaccinated animals. The essence of any vaccine must be that it is safe and capable of eliciting a protective response in the targeted host. This could mean protection from clinical disease or protection from infection by the pathogen, and a criterion for protective efficacy must be established for each disease for which a vaccine is to be developed. Protection does not mean that the vaccine constituents are immunogenic or antigenic, or that they elicit neutralizing antibodies. Although correlations between an in vitro serum neutralizing antibody and protection against disease do exist for some diseases, there are other diseases in which neutralizing antibody activity and protection from disease are not well correlated. For some diseases, cell-mediated immunity (CMI) is more important. Protective immunity can be established only by challenge of the vaccinated host for which the vaccine is intended with the respective pathogen under conditions resembling those of natural infection. Challenge models are an important part of vaccine efficacy testing, along with assessment of vaccine-induced immune responses and field trials. However, the ultimate test of any vaccine for the veterinary practitioner,

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livestock producer, and the animals is protection or disease sparing, following proper use of the vaccine in field situations in which natural transmission of pathogens occurs. Although laboratory challenge models are an approximation of this situation, they are, by definition, artificial and often fail to duplicate the multiplicity of factors that comprise disease following exposure to pathogens. Naturally occurring dose, frequency of pathogen exposure, and the kinetics of animal-to-animal transmission in a herd are three such factors that are difficult to duplicate in challenge models but obviously could affect the outcome of a test of vaccine efficacy.

Expected Benefits of Vaccination. Vaccination programs are designed to potentiate the immune system of the host toward a unique, specific antigen and to prevent clinical disease caused by that specific antigen. For example, vaccination against infectious bovine rhinotracheitis in cattle is expected to provide protection against clinical disease and to protect the fetus of pregnant cattle. The control of transmission of disease within herds is one of the objectives of an effective vaccine, and transmission can be measured experimentally. Using Aujeszky's disease as an experimental model, it has been shown that vaccinating pigs twice significantly reduces disease transmission (DeJong and Kimman, 1994). In unvaccinated groups the estimated maximum number of secondary cases per infectious individual (the basic reproduction ratio R0) was 10.0. In contrast, the reproduction ratio for the vaccinated groups was 0.5. Thus it is possible to measure transmission experimentally. Ideally, such measurements should be obtained for all vaccines intended to eliminate etiological agents causing infectious diseases, either on a single farm or in a country. The potential of a vaccination program to eliminate infection from the host population and the proportion of hosts that must be vaccinated to achieve elimination are related to the basic reproduction number of the pathogens or parasite and to the impact of the vaccine. The impact of the vaccine is a measure of the take of the vaccine and the duration of protection. Duration of protection should be a major consideration in the development of new vaccines (Woolhouse et al, 1997). The interval between repeat vaccinations is related to vaccine impact, host life expectancy, and the basic reproduction ratio. For a pathogen with a high basic reproduction number, and where available vaccines have low or moderate impact, it may not be possible to eliminate infection regardless of how frequently hosts are vaccinated.

Mastitis vaccines are expected to eliminate chronic intramammary infections, prevent the establishment of new intramammary infections, and reduce the frequency and severity of clinical disease (Sordillo et al, 1997). But vaccines currently available do not reduce consistently the incidence of new intramammary infections or eliminate chronic mastitis. However, some mastitis vaccines have effectively reduced the incidence of clinical mastitis. For example, recent development of the R mutant vaccines for Gram-negative mastitis should prove to be beneficial for the control of coliform mastitis in well-managed dairy herds (Sordillo et al, 1997).

HUMORAL IMMUNITY. The protective immune response to a vaccine may be due to the presence of circulating antibody (humoral immunity), the actions of sensitized T-lymphocytes (CMI), the presence of antibody on mucosal surfaces (mucosal immunity), or a combination of these factors. Assessing vaccination with serology is attractive. Unfortunately, measuring circulating antibody is not necessarily synonymous with protection. For most diseases, it is not clear what level of antibody is required for protection, nor are standardized serological methodologies used in all laboratories that would allow comparison of results between laboratories. In addition, some pathogens persist in a latent form despite a host immune response. An excellent review of the theory behind diagnostic serologic testing and the strategies for interpreting the results of these tests is available (Tyler and Cullor, 1989).

CELL-MEDIATED IMMUNITY. Immunological evaluation of vaccines has depended largely on the measurement of an antibody response in the serum of recipient animals. This approach works well for diseases prevented in large part by humoral immunity but ignores the contributions of CMI or the contributions made by mucosal immunity in providing protection against many infectious diseases. As a result of this approach, certain vaccines have been marketed that produced an antibody response but failed to protect vaccinates in the field from disease. In a rational approach to vaccine development, some questions must be addressed when assessing the development of CMI against a specific disease. Does CMI have an important role in providing protection against the disease? What are the CMI responses that develop after vaccination or natural infection with the infectious agent, and how can these responses be measured? Which antigenic components of the infectious agent are targets of the protective CMI responses? Which CMI effector functions provide protection against the disease? What vaccination strategy (antigen delivery system, adjuvant formulation) induces the most protective CMI response against the infectious agent? Many diseases require that a CMI response develop in the host to provide adequate immune protection. Extensive knowledge of the CMI responses to infectious agents is required when a rational approach to improved vaccine development for these diseases is attempted (Clough and Roth, 1995). The importance of CMI against a specific disease may be examined by determining that induction of an active antibody response or the acquisition of passively acquired antibody to the causative agent does not correlate well with protection against clinical disease. It is usually assumed that if antibodies do not prevent clinical disease, then other immune mechanisms (cell mediated or mucosal) must be important for protective immunity (Clough and Roth, 1995).

The importance of CMI in providing protection against specific diseases may be assessed by suppressing a specific arm of the immune system and evaluating the severity of disease after subsequent challenge exposure.

Measurement of CMI can be accomplished using several different assays, including delayed hypersensitivity, leukocyte migration inhibition, adoptive transfer, lymphocyte proliferation, cytokine release, and cytotoxicity assays (Clough and Roth, 1995).

The CMI response after natural infection is not necessarily the same as that induced by vaccination. The duration of vaccine-induced CMI may differ from the duration of CMI induced by natural infection. In general, the duration of vaccine-induced immunity has not been well defined. Most veterinary vaccine studies have detected initial vaccine efficacy, but the immune responses beyond several weeks after vaccination have not been monitored. In nearly all vaccine studies, protective immunity over time is determined by challenge-exposure or serological methods, and few studies have measured CMI responses over an extended period (Clough and Roth, 1995).

Identification of protective microbial antigens is important in implementing a rational immunological approach to vaccine development. Knowing the protective antigens facilitates the selection of vaccine strains for whole cell vaccines. The strain must express the protective antigens and stimulate solid immunity to those antigens. The type of antigen that elicits a protective immune response varies widely among infectious agents. Thus careful selection of the ap-

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propriate antigens for inclusion in these vaccines is critical to the efficacy of the final product.

The method of antigen delivery may be as critical to the efficacy of a vaccine as the selection of protective antigens to include in the vaccine. Antigen presentation influences the types of immune responses that are generated in host animals, and the type of immunity favored should correspond to the immune mechanism that has been identified as protective. Current research aimed at increasing the CMI response to vaccines include improved adjuvant formulation, generation of vaccine vectors, and the development of bioengineered delivery systems.

LACTOGENIC IMMUNITY. For some important diseases of swine and cattle, lactogenic immunity is important. An excellent example is transmissible gastroenteritis of swine. The disease is caused by a virus and is the major cause of neonatal diarrhea in piglets, causing up to 100% mortality in piglets under 2 weeks of age. Recovery from natural infection imparts a high degree of resistance to reinfection, but active immunization cannot be induced in time to protect neonatal piglets when they are most susceptible. Neonatal pigs are dependent on passive immunity transferred from the sow's colostrum and milk (lactogenic immunity, coproimmunity). Commercial vaccines have limited efficacy under simulated field conditions. Numerous studies have emphasized the importance of IgA antibodies in colostrum and milk in passive immunity. Sows inoculated with virulent virus orally secrete IgA antibodies in colostrum and milk and provide a high degree of protection to their piglets. However, it has been difficult to attain comparable colostral and milk IgA antibodies using attenuated live virus vaccines, probably because of limited replication of the virus in fewer enterocytes. Vaccination of sows with attenuated live transmissible gastroenteritis virus or a recombinant virus vaccine failed to provide complete protection to suckling pigs after challenge exposure (Park et al, 1998).

Approval of Vaccines. Although national departments of agriculture may be responsible for licensing vaccines, licensing authorities do not conduct clinical field trials to evaluate vaccines against naturally occurring diseases. Currently, the vaccines are approved on the basis of data supplied by the manufacturers, who usually claim efficacy based on serological responses following vaccination of host animals and protection against experimentally induced disease in a host animal and in vitro tests. These test results usually cannot be correlated with protection against naturally occurring diseases. Furthermore, the data submitted by the manufacturer to the licensing agency involve privileged information and are not available to the veterinary profession at large for peer review. It seems unjustifiable not to disclose the efficacy data to veterinarians who must recommend the use of the vaccine to the livestock producer. Furthermore, when veterinary research workers conduct well-designed field trials and find that a particular vaccine is not efficacious, the information can be ignored by the licensing agency and the vaccine continues to be sold.

Until recently, the biologics manufacturers did not conduct scientifically designed field trials on typical livestock farms using randomly assigned, unvaccinated control animals along with vaccinated animals to show protection against naturally occurring diseases. The manufacturers have contended that livestock producers are reluctant to permit the use of control animals. They claimed that producers sometimes charge the manufacturers unfairly for losses that occur during the study. The manufacturers also state that, because the incidence of many diseases is low and the occurrence too difficult to predict, this type of testing requires too many animals, which makes the trial expensive and prohibitive because of the limited market for food animal vaccines. However, there are signs of progress. Biologics manufacturers have now begun to support well-designed field trials to evaluate the efficacy of vaccines against naturally occurring diseases (Van Donkersgoed et al, 1990b). Also, when the need for field trials with concomitant controls is explained to producers, they cooperate and participate in the evaluation of vaccines and other biologics. The evolution of the vaccines for bovine pneumonic pasteurellosis is an example of the value of intensive and focused research on the pathogenetic and microbiological mechanisms of a disease entity.

There is a widespread belief among vaccine users that efficacy can be determined accurately through extensive field usage of a vaccine against naturally occurring disease in the absence of control animals. This belief may be acceptable for those diseases that are clearly defined and relatively easy to diagnose, such as blackleg. With the more complex problems, however, such as diarrhea and pneumonia, accurate field evaluation of a vaccine without good experimental procedures and design, including adequate numbers of randomly assigned control animals in the same population, is difficult and often leads to erroneous conclusions. For example, an apparent decrease in the losses caused by acute diarrhea in a beef herd or by respiratory disease in feedlot animals following vaccination of all animals in either situation in 1 year compared with the previous year or feeding period may not be related to the use of the vaccines. There is a lack of understanding of why the incidence of diarrhea in beef calves varies from herd to herd, from year to year, and within the same calving season in large herds. In addition, the fact that it occurs in some animals and not in others necessitates that well-designed field trials be conducted if the results are to be meaningful and can be applied to other herds in general.

The herd effects in trials of animal biologics must be considered (Waltner-Toews, 1989). Even in well-designed field trials and with all the modern tools of veterinary epidemiology, considerable difficulty is commonly encountered in making the definitive, causative diagnosis of clinical cases that occur in both vaccinated and unvaccinated control animals. For example, how is the cause of acute diarrhea determined in a particular group of calves from which two or more enteropathogens were isolated from the feces of affected calves born from cows vaccinated with a vaccine intended to prevent diarrhea caused by the same pathogens? The same applies for acute undifferentiated bovine respiratory disease in feedlot cattle that are vaccinated with an *M. haemolytica (P. haemolytica)* vaccine.

Meta-analysis of various vaccines for the control of specific diseases is being done now. The analysis controls for all the relevant variables that affect vaccine efficacy comparisons. For example, a meta-analysis of the various commercial vaccines available for a 12-year period for the control of pneumonic pasteurellosis in cattle has been published (Srinand et al, 1996). Such analysis allows for an objective comparison of the efficacy of several vaccines. Box 4-2 offers some possible approaches to resolving the problem of vaccine efficacy.

It could be argued that governmental authorities (licensing bodies) should not be given the power to deny access by the livestock industry to new products based on efficacy in the field regulations. There is no single, perfect trial. Only by the use of multiple, properly designed trials, carried out under field conditions, can the efficacy for many products be assessed. The biologics manufacturers should be required to ensure there are no major problems with the product, and the livestock industry, including producers, veterinarians, and epidemiologists, then can assess properly vaccine efficacy.

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BOX 4-2

Approaches to Resolving the Problem of Vaccine Efficacy

1. The vaccine user should be informed that the licensing agency determines efficacy on the basis of the data generated by the manufacturer.
2. Licensing regulations should require that vaccines, before licensure, be shown to be efficacious in properly designed studies. The results of these experiments should have proven correlation with protection against the naturally occurring disease in the host animals. The other tests, including serological responses, protection against experimentally induced disease, and certain in vitro tests are valid to use for this purpose only if it can be shown that their results correlate significantly with protection in the host animal against naturally occurring disease.
3. Vaccines should be evaluated following licensing. An objective and open evaluation of licensed biologics is needed to provide the vaccine user with information necessary to make informed decisions regarding vaccine use. For example, the approval of the vaccine for the control of pneumonic pasteurellosis has been evaluated by veterinary clinicians who conducted field trials with unvaccinated control animals. The results were published in the Canadian veterinary literature. The same has been done for the bovine respiratory syncytial virus vaccine and others.

Adverse Vaccine Reactions. During the process of development of a vaccine, the manufacturer must show that the vaccine stimulates an immune response and that it is safe for use in the target animals. Since the development of combination vaccines for use in livestock, there have been reports of adverse reactions associated with the use of some vaccines. Most reports are anecdotal, making it difficult to assess mechanisms by which certain vaccine components, or combinations thereof, may cause adverse reactions. Combination vaccines containing viral and bacterial antigens are commonly used in veterinary practice and have been associated with adverse reactions (Ellis and Yong, 1997). It is suspected that the presence of endotoxin or other bacterial components may interact with adjuvants to cause an enhanced pathological inflammatory response in some individuals (Ellis and Yong, 1997). Vaccination of calves between 3 and 31 days of age with a combination of multiple-antigen vaccines containing known quantities of endotoxin can induce evidence of an inflammatory response characterized by a fever, increased total white blood cell counts, and absolute neutrophil counts, without clinical signs of illness (Allen et al, 1996).

Vaccine Assessment Checklist. If efficacy data are not available from the vaccine manufacturer, the practitioner then must assess the effectiveness of the vaccine based on whatever clinical research on the vaccine has been published. A vaccine assessment checklist can be used by the practitioner to make an informed decision about recommending the use of a certain vaccine (Ribble, 1990). The important items in a vaccine assessment checklist are shown in Box 4-3. In addition to this checklist, the veterinarian must consider all relevant circumstances in the herd on a regular basis and determine how effective the vaccine might be in that herd compared with another.

Design of a Vaccination Program. A number of factors should be considered when providing recommendations for the use of vaccines and vaccine schedules, including those in Box 4-4. Deciding to recommend the vaccination of any of the food-producing animal species for protection against an infectious disease primarily depends on the probability of infection occurring and causing economically important clinical disease without vaccination. Also, the availability of an efficacious vaccine that can provide protection so that the incidence of clinical disease is lower than if the animals were not vaccinated is an important factor. For each of the infectious diseases that are likely to occur in a particular area, there is usually some epidemiological information available that can be used to predict the probability of infection and disease occurring. This information can be applied to the herd under consideration. Ideally, a cost-benefit analysis would be performed, but, under most practical conditions, the information required for such an analysis is neither available nor reliable. As a result, most veterinarians justify the use of a vaccine based on their assessment of the probability that the disease will occur at a certain incidence if the animals are not vaccinated and that vaccination will provide varying degrees of protection and be cost effective. Obviously, there is a need for more reliable information on the probable incidence of disease with and without vaccination in herds with varying levels of management and risk factors.

Guidelines for the use of biologics in domestic animals are issued periodically by the Council on Biologic and Therapeutic Agents in the United States. The guidelines are intended to document currently accepted protocols for vaccinations, based on the best available scientific information (Council Report, 1994). However, these guidelines are not based on the results of randomized field trials under naturally occurring conditions.

Time of Vaccination and at What Intervals. For most vaccines, both primary and secondary vaccinations are recommended for optimal protection. In general terms, the primary vaccination is the first time the vaccine is given, followed by a second vaccination usually 10 to 28 days later. Two vaccinations at that interval usually cause a higher titer 10 days after the second vaccination compared with that after only one vaccination. Most recommendations in the literature are for two vaccinations for the primary vaccination. Whether the higher titer is more protective or more economically beneficial is uncertain. In general, most primary vaccinations for the commonly occurring infectious diseases of food-producing animals are given at least 2 weeks before the expected occurrence of disease. Young animals are usually vaccinated after the colostral immunity has waned. For infections that cause fetal disease, the breeding female should be vaccinated at least 3 weeks before breeding.

The vaccination of the pregnant female in late gestation is an effective method for the passive immunization of the newborn against commonly occurring infectious diseases (Saif and Fernandez, 1996). The widespread occurrence of rotavirus antibodies in the colostrum led to strategies for maternal rotavirus vaccination to boost lactogenic immunity and transfer passive antibodies to the neonate through colostrum and milk (Saif and Fernandez, 1996). The variable success of maternal rotavirus vaccines in the field is influenced by vaccine dose, strain of virus, inactivating agent, adjuvant, route of administration, and environmental rotavirus exposure levels. The use of genetically engineered rotavirus-like particle vaccines in cows to boost antibodies in mammary secretions shows promise and possesses potential advantages over existing vaccines.

Administration of modified-live viral vaccines can boost systemic humoral and cellular responses to BRSV and bo-

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BOX 4-3

Vaccine Assessment Checklist

1. Has the vaccine been laboratory and field tested in randomized, controlled trials? This requires the results of testing in the laboratory and field, and often these are not available.
2. Were the control groups concurrent or historical? Were control groups of animals randomly assigned at the same time as the vaccinated groups? Historical control groups (those not vaccinated in previous years) are unsatisfactory for comparison.
3. How were the trial animals challenged? In a laboratory study of the efficacy of the vaccine, assess how closely the challenge model approaches the natural disease and whether the results can be extrapolated to the field situation. In field trials, note whether the controls became clinically affected, and note the incidence of clinical disease.
4. Was the measure of outcome meaningful? The outcomes should be easily measurable so that there is clear evidence that the vaccine prevents clinical disease. Outcomes include morbidity and mortality caused by the disease in question and production measures, such as average daily gain. Often, morbidity rates are actually treatment rates based on the number of animals that became sick and were treated. Thus the morbidity rate by itself may not provide a true indication of whether the vaccine protected the animals against the specific disease compared with the controls. The ideal situation would be to make a precise clinical and laboratory diagnosis of the diseases that occurred in both the vaccinated and unvaccinated animals. The serological response in vaccinated animals is often used as measure of efficacy, but it really does not indicate whether the vaccine prevents disease or improves production.
5. Were the biology and epidemiology of the disease considered?
6. Was the vaccine assigned randomly? Some type of randomization procedure is necessary so that each animal has an equal chance of being assigned to the vaccinated or control group.
7. Were blinding techniques used to reduce bias? Both the vaccinated and control groups of animals should be handled similarly, and the animal attendants responsible for the detection and treatment of sick animals should not be able to distinguish the vaccinated animals from the controls. This means that the method of identification, such as an ear tag, is identical in both groups and that the vaccination status of each animal is not revealed until the end of the trial.
8. What other potentially important biases are evident? Some potential biases occur in almost every field trial, and their significance must be assessed.
9. How likely was the result a chance finding? Rather than depend on the statistical significance of the results, it may be more meaningful to estimate the magnitude of the vaccine effect and the accuracy of that effect.
10. What are the differences between the trial animals and animals in a private veterinary practice? How relevant are the results of the field trial to herds in a private practice?

vine herpesvirus-1 in cows. Neonatal calves can be immunologically primed by vaccination at 10 days of age with modified-live virus vaccine based on virus-specific memory cells persisting in most calves until weaning (Ellis et al, 1996a). Vaccination of pregnant cattle with the intranasal vaccine for bovine herpesvirus-1 provides protection of the calves against the highly fatal form of the infection, which can occur in newborn calves (Mechor et al, 1987).

Vaccination of newborn calves under a few days of age with a modified-live bovine herpesvirus-1 and parainfluenza-3 virus vaccine has been associated with a high mortality (Bryan et al, 1994).

The effects of the presence of maternal antibodies in young farm animals on active immunization have been suggested as a cause of vaccine failure, but it is not documented. The vaccination of pregnant cows 4 months before calving results in colostral titers in calves, which can be enhanced by vaccination of the calves at 50 to 53 days (Troxel et al, 1997).

For feedlot cattle, the ideal procedure is to vaccinate them at least 2 weeks before being placed in the feedlot and mixed with other cattle. However, under commercial feedlot conditions, in which cattle are bought from auction marts and sent directly to the feedlot, the animals are invariably vaccinated on or shortly after arrival.

A common question about vaccination schedules for food-producing animal herds is the frequency with which animals should be revaccinated upon receiving their primary vaccination. Should dairy cows, beef cows, breeding sows, and ewes be revaccinated annually for protection against commonly occurring diseases if they were vaccinated once or twice when they were young? Based on the principles of immunology, a booster vaccination or revaccination usually is given annually or sometimes biannually depending on the disease being considered, the nature of the vaccine, the immunogenicity of the antigens, the duration of immunity provided by the vaccine, and the degree of infection pressure that is anticipated. For some diseases of cattle, for example, unless booster vaccinations are given or reinfection occurs to stimulate an anamnestic response, herd immunity wanes in 2 to 3 years and booster vaccinations should be considered. A similar situation applies in swine herds, in which sows are vaccinated for some diseases before or during each pregnancy. However, some of these practices are based on empirical observations; there is often no reliable published information on which to base a recommendation to revaccinate every few years or during every production cycle.

Vaccines are sometimes used during a herd epidemic in an attempt to prevent additional new cases among unvaccinated animals. All the in-contact normal animals are vaccinated based on the assumption that they have not been infected already by contact with the clinically affected animals. In outbreaks of anthrax, for example, the vaccination of all in-contact animals is highly effective for the prevention of new cases. The same applies for outbreaks of blackleg in unvaccinated cattle. The use of vaccines in the face of an outbreak of acute bovine respiratory disease depends on the

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BOX 4-4

Design of a Vaccination Program

1. What are the risks of infection and clinical disease occurring in the animals in question without vaccination?
2. What are the potential economic losses associated with the clinical disease in unvaccinated animals?
3. What risk factors for the disease are present in the herd or are likely to be present in the future, and can they be removed or modified as part of the control program?
4. Can the disease be prevented or controlled economically and practically in the herd under consideration without the use of vaccines?
5. What type of immunity is required for protection of the disease(s) under question? Is it humoral, local, or cell mediated, and what type does the vaccine stimulate?
6. What information is available about the efficacy of the vaccine, and how much protection can the vaccine provide in the circumstances under consideration compared with not vaccinating? How successful has the vaccine been in the past in the herd under consideration? Can the vaccine prevent both clinical disease and infection? What are the results of a crude cost-benefit analysis based on the expected economic losses associated with morbidity and mortality in the vaccinated and nonvaccinated groups, considering all costs associated with the vaccine and the vaccination procedure?
7. If vaccination of the newborn is being considered, does the presence of colostral immunity minimize the effects of the vaccine?
8. If the vaccine under consideration is a live vaccine, are there any potential hazards associated with its use in the animals to be vaccinated? Modified live virus vaccines are potentially abortigenic and should not be used in pregnant animals. The use of modified live virus vaccines can result in the shedding and spread of the vaccine virus to other animals, but this is an unlikely occurrence.
9. What is the duration of immunity provided by the vaccine? How often must the animals be revaccinated?
10. Should the vaccine ever be used during an epidemic of the disease in the herd in an attempt to prevent additional new cases?

suspected cause of the disease, the class of animals involved, and the potential for long-term economic losses. In an outbreak of infectious bovine rhinotracheitis in an unvaccinated dairy herd, the potential for abortion is high and vaccination of all animals, including vaccination of the pregnant cows with a nonabortigenic vaccine, is recommended. The use of respiratory virus vaccines or the *M. haemolytica (P. haemolytica)* vaccine in the face of an outbreak of acute respiratory disease in recently arrived feedlot cattle does not make biological sense. Many of the animals are under stress, some are incubating the disease, and vaccination actually may cause an increase in the incidence of disease.

Vaccination of Wildlife Vectors. The control of bovine tuberculosis in the United Kingdom is a major problem because of the reservoir of *M. bovis* infection in badgers (Newell and Hewinson, 1995) and in New Zealand because of the reservoir of infection in the Australian brushtail possum *(Trichosurus vulpecula)* (O'Neil and Pharo, 1995). The possibility of controlling the disease by vaccination of cattle or farmed deer is unpopular because of the potential compromise of existing diagnostic tests. However, the vaccination of badgers to reduce the risk of transmission to cattle is an attractive option and now has been adopted as a potential control strategy (Newell and Hewinson, 1995). An initial strategy appears to involve optimization of bacille Calmette-Guérin (BCG) vaccination or the cloning of mycobacterial antigens into BCG. Given a suitable delivery system, aerosol vaccination of possums with the BCG vaccine combined with other control measures may be a suitable method of reducing the spread of *M. bovis* from wildlife to domestic animals (Aldwell et al, 1995).

Recommending a Vaccine and a Vaccination Schedule. As part of a comprehensive, year-round, health management program, veterinarians have the opportunity to make recommendations about the selection of vaccines and the vaccination schedule. The veterinary practice can educate clients about the need to vaccinate and when to vaccinate through regular newsletters. This method is effective because it prompts many questions from producers, which results in contact between the veterinarian and the producer. More importantly, however, veterinarians must become familiar with the herd, identify and assess the importance of risk factors, monitor the disease incidence, anticipate when the infectious diseases are to occur, make appropriate control recommendations (including the management techniques to reduce risk factors), and recommend the vaccines to be used and the vaccination schedule. Recommendations should be submitted in a written report, which may include observations about disease control made by the veterinarian during farm visits. The recommendations should include the following:

- *Which diseases* are being controlled by vaccination
- *Which animals* should be vaccinated including all age groups
- *Which vaccine* should be used
- *When* the vaccines should be used during the lifetime or production cycle of the animal
- *Frequency of vaccination* or when a booster vaccine should be given

The level of protection that can be expected from the vaccine should be estimated and explained. Producers should be encouraged to record the date on which they vaccinated the animals and the brand name and batch number of the vaccine used. It is remarkable how easy it is to forget vaccination dates or whether certain animals were actually vaccinated. It is also important to advise producers about the logistics of the use of the vaccine, how it should be stored, whether unused portions can be used at another time, the route of administration, the proper use of needles and sy-

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ringes, and the hazards of chemical sterilants when using a live vaccine. With the possibility that certain infectious diseases such as bovine leukosis can be transmitted by the use of hypodermic needles, it may be necessary to use a *new needle* for each animal. When disease for which the animals are vaccinated occurs in vaccinated animals, the veterinarian should investigate the problem, attempt to make a clinical and laboratory diagnosis, communicate the results to the vaccine manufacturer, and explain to the producer the possible causes of the apparent failure of the vaccine and the disease control program. Veterinary records of herd investigations assume high priority in such occurrences.

The effect of vaccines and other injectables like antimicrobials on the formation of injection site lesions in food-producing animals is now a major concern (Van Donkersgoed et al, 1999a). Injection site surveys in feedlot cattle in Canada and the United States have found injection site lesions in primal beef cuts, which are a major cause of economic loss in the beef cattle industry because of losses in trim, devaluation of cuts, and consumer dissatisfaction from eating tough beef. The occurrence and severity of lesions may vary with location of injection. They are less severe in the blade than in the butt or round because the products are introduced intermuscularly (between muscles) in the neck because of the presence of numerous fascial planes. The intermuscular location and the excellent lymphatic supply in the neck may result in accelerated absorption of products and rapid healing. A high incidence of intramuscular lesions associated with the use of clostridial bacterins has resulted in recommendations to administer these vaccines subcutaneously in the neck. The use of chemically altered and modified-live virus vaccine combinations given intramuscularly in primal cuts is also associated with a high incidence of lesions, which may be due to the presence of oil-based adjuvants in the vaccines. Myositis, lameness, and paraparesis have been associated with the use of an oil-based adjuvant bacterin administered intramuscularly (McAllister et al, 1995). Vaccination into paravertebral muscles is risky because inflammation may extend through intervertebral foramina.

Compliance of the Animal Owner with the Recommendations of the Veterinarian. The success of any animal health management program is limited by the willingness of the producer to implement any of the program components. Several factors influence this willingness, but in most cases the predominant considerations are about the effectiveness of the program ("Does the herd need it and will it work?") and about its cost; the producer must have confidence that implementing the program will be effective and that the program is valuable. The program should provide a return on their investment, or at least they should be confident that the program will reduce potential financial losses.

Surveys of vaccination practices in dairy herds indicate that a large percentage of dairy cows and heifers are not vaccinated against bovine virus diarrhea at all or improperly vaccinated (Rauff et al, 1996; Carruthers and Petrie, 1996). In 1993 to 1994, outbreaks of fatal mucosal disease occurred in dairy herds in Canada and the United States. Field investigations revealed that affected herds had not been vaccinated or had been vaccinated improperly by failing to provide a booster vaccination 2 to 4 weeks after the initial inactivated vaccine was given. Veterinarians could be more effective in providing specific vaccination recommendations and infectious disease control programs to their dairy producers as part of health management programs. In a survey of Saskatchewan dairy farms in 1994, only 34% of the dairy herds were vaccinated against BVD virus, compared with a reported 58% of dairy herds in the United States and Ontario in which, at a minimum, the heifers were vaccinated (Carruthers and Petrie, 1996). Surveys of beef cow-calf producers have found that veterinarians have an excellent opportunity to advise producers about infectious disease management, especially vaccination programs (Sanderson and Gay, 1996).

Producers expect their veterinarians to help assess the degree of risk reduction provided by the program; essentially, will the disease-control program be effective and cost effective? The veterinarian must be familiar with the local disease conditions and any factors in the producer's herd that might alter (either increasing or decreasing) their risk. The challenge for the veterinarian is how to effectively communicate the risk so producers will want to adopt the program. Each herd visit is an opportunity to present this information verbally, but providing concise specific written recommendations may increase producer understanding and acceptance of recommendations. The written recommendations may be general as in articles in a practice newsletter sent to all producers in your practice. But compliance may be increased if specific recommendations are made for the farm in the form of a "preventive prescription." The owner must be fully informed by the veterinarian about the importance of vaccination, which vaccines to use, when to use them, and their limitations. The veterinarian should provide explicit written recommendations and monitor compliance by asking the owner if the animals were vaccinated, on what date, and with which vaccine. The veterinarian must show leadership and be responsible for monitoring the health management in the herd.

Whether the producer accepts the program or not, the veterinarian may have an obligation to educate the producer about the merits and limitations of the preventive program. In human medicine, education of the patient is often ineffective in increasing compliance. Large-animal practitioners have an advantage over their human colleagues because they actually visit their clients rather than wait for patients to return to them. This provides veterinarians opportunities to reinforce their message about adopting preventive measures. Although education may not increase compliance, client education programs are probably valuable in maintaining the acceptance of procedures by current users. Using education to improve compliance is most effective when information is presented in a variety of ways and when there is continual reinforcement of the message. Making individual and group contact (such as producer meetings), giving written as well as verbal recommendations, and using examples of some successful programs or failures by other producers are all strategies that can be used to try to improve compliance.

If producers do not accept all or part of a disease prevention program, should veterinarians alter their recommendations until a program is reached that the producer will accept? What components can be removed before the program reaches a point when it is unlikely to be effective? This problem became an actual concern in Ontario in 1993 (Carman et al, 1998). In that situation, many producers apparently had been reluctant to administer a double primary immunization series when killed BVDV vaccines were used. The reasons often presented for lack of compliance to appropriate vaccination procedures were the additional cost and inconvenience of handling animals twice. When some of these "partially" vaccinated herds had severe problems with BVD, questions were asked about whether veterinarians should have permitted producers to adopt an ineffective vaccination protocol. Should veterinarians permit this type of situation to occur or should they refuse to administer a vaccination program that they know will be ineffective? Veterinarians may have a legal as well as an ethical responsibility for the failure of inadequate programs.

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Proper implementation of vaccination protocols is necessary to optimize efficacy of vaccines. Periodic reviews of the management practices in a herd are necessary to ensure that the vaccinations are actually done. In some situations the employees responsible for vaccinations actually may not vaccinate the animals or may vaccinate them inadequately (Amass and Scholz, 1998).

Economic Analysis of Vaccination. An economic model of the costs and benefits of vaccination has been proposed based on its application to the control of listeriosis in sheep in Norway (Vagsholm et al, 1991). Four items of information are needed: (1) the cost of a clinical case, which includes the cost of treatment and the average cost of mortality (average case-fatality rate multiplied by the value of the animal), (2) the annual total cost of vaccination of each animal, (3) the expected incidence of the disease, and (4) the efficacy of the vaccine.

The incidence of disease at which vaccination should be recommended is given by the equation:

$$EI > VC/(DC \times VE)$$

where *EI* is the expected incidence, *VC* is the annual cost of vaccinating each animal, including any veterinary fees associated with vaccination, *DC* is the cost of a clinical case, including treatment and average cost of mortality (average percentage case-fatality rate multiplied by the average cost of the animal), and *VE* is the efficacy of the vaccine, given by the following:

$$VE = \frac{1 - (\text{Number of diseased vaccinated animals})}{\text{Number of diseased unvaccinated animals}}$$

The derivation of the equation is as follows: (Vagsholm et al, 1991). The basic premise of the model is that vaccination should prevent losses that are larger than or equal to the costs of vaccination. This is expressed by the equation:

$$(RI \times DC) > VC \qquad (4\text{-}1)$$

where *RI* is the proportional reduction in annual incidence of disease resulting from vaccination, *DC* is the cost of a clinical case, including treatment and average cost of mortality (average case-fatality rate multiplied by the average cost of the animal), and *VC* is the annual cost of vaccinating each animal, including any veterinary fees. This expression can be rewritten as follows:

$$RI > (VC/DC) \qquad (4\text{-}2)$$

Equation 4-2 indicates that the proportional reduction in disease incidence that is required to make vaccination beneficial is a function of the ratio of the cost of a vaccination to the cost of a disease case. To estimate the expected incidence (EI) at which vaccination would become beneficial, the efficacy of the vaccine (VE) must be estimated, as given above. Vaccination should be recommended when the expected incidence (EI) is larger than the reduction in disease incidence (RI), defined as the ratio of the cost of a vaccination to the cost of a disease case divided by the efficacy of the vaccine:

$$EI > (RI/VE)$$

Substituting for *RI* from Equation 4-2, the incidence of disease at which vaccination should be recommended is given by the equation:

$$EI > VC/(DC \times VE)$$

Because the estimated costs of vaccination and disease are average values, the incidence of disease at which vaccination should be recommended can be determined according to variations in the costs of vaccination and the value of the animal, which may vary widely. A table can be structured that lists the expected percentage incidences of disease above which vaccination would be economically beneficial according to the cost of vaccination and the value of the animal.

The disease under consideration and the expected efficacy of a vaccine to control that disease influence the choice of a vaccine, and the formulation of a control program may or may not include the use of a vaccine. For some of the causally defined diseases, such as rabies, erysipelas, and the clostridial diseases, the vaccines available are usually effective and reliable. For others, such as leptospirosis in cattle, some of the vaccines available may not be effective because the antigens used in the vaccines are not specific enough to stimulate immunity against the field serotypes of leptospira causing the disease. For complex diseases not causally defined, such as acute undifferentiated diarrhea of calves and acute bovine respiratory disease of feedlot cattle, the vaccines available are often not effective. In both these cases, several different pathogens in combination with a variety of risk factors are often the causative factors.

Surveillance of Disease Prevalence

The prevalence of an infectious disease in a herd can be monitored indefinitely as a method of control. The control of Johne's disease in a herd is an excellent example of such continued surveillance. The first herd diagnostic step in a control program is to test all animals over 2 years of age and to consider culling all seropositive animals. After the ELISA-positive animals are culled from the herd, a second ELISA can be done on the entire herd again. An alternative is fecal culture, which is more expensive but detects animals missed by the ELISA. It is suggested that every third or fourth test should be a fecal culture. The frequency of testing and the types of tests used depend on factors such as the type of farm enterprise and the use of the animals, the estimated prevalence of infection, the owner's perception of the importance of the disease and how it has affected productivity, the willingness of the owner to invest in the costs of the tests, how quickly the owner wishes to begin a control program, and the eagerness of the owner to control the disease.

When the incidence of infection in a herd is low, continued progress towards certification that the herd is free of infection is a desirable goal. This is achieved by continued testing of the herd and testing replacement animals that are being introduced to the herd. A model herd certification program for Johne's disease was adopted by the U.S. Animal Health Association in 1993. The goal of the program is to establish uniform herd certification standards among the states. Identification of herds free of infection is vital to preventing spread of infection nationally and internationally. Certification of laboratories in performing the diagnostic tests such as being able to culture the organism is an important part of the program. The model herd certification program consists of using the ELISA and an organism detection test such as fecal culture on an alternating basis annually on all animals in the herd more than 20 months of age. Herds are given levels of certification based on the number of herd negative tests up to level 5. After attaining a level 5 Johne's-free certification, herds can maintain certification by retesting annually with either a serum antibody test or organism detection-based test.

Testing herd replacements before they are nominated for breeding (15 months of age) would be desirable, but the available tests are unlikely to detect subclinically infected animals at that age. Herds become infected by the introduction of unknown subclinically infected animals. The estimated risk of purchasing an infected animal from an auction mart of cattle dealer is 10% based on the overall

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prevalence of infection in the cattle population. Ideally, purchased herd replacements should be obtained from certified paratuberculosis-free herds. If these are not available, the next best option is to purchase from herds that have had no recent history of clinical disease. Then a prepurchase plan should be arranged with the seller to test the animals, and the costs should be determined. If the seller is unwilling to cooperate with a prepurchase testing as a condition of sale, the buyer may wish to purchase the animal and quarantine it until testing on the farm is completed. The ELISA is recommended for purchased animals, but replacement heifers 12 to 15 months of age are unlikely to be seropositive, and fecal culture would improve the accuracy of testing.

When the prevalence of disease in a herd or geographic area has been reduced to a low level or even eliminated, a surveillance system is desirable to monitor the infection rate and to prevent the introduction of unknown infected animals into the population. This can be established by requesting that imported animals be certified free of specific diseases and be placed in quarantine for specific periods, combined with diagnostic testing to ensure that they are negative for the disease in question. Bulls destined for artificial insemination units are to be tested for several infectious agents and must be found negative before they are allowed entry (Howard et al, 1990).

In countries with national programs for the eradication of a disease such as bovine virus diarrhea in dairy herds, the testing of bulk tank milk for the presence of antibodies is an excellent diagnostic aid for detection of infected herds that have not been vaccinated (Fredriksen et al, 1998). In Norway, a national program was introduced in 1992 to eradicate BVDV. No BVDV vaccines are used, and all milk-positive herds are followed up by examination of pooled milk samples from heifers and, if antibodies are detected in these, also by examination of pooled blood samples from calves. The presence of antibodies in blood and milk is always the result of natural infection.

Mass screening of livestock herds for selected infectious agents can be done using ELISA methods on sera (Behymer et al, 1991). The data provided from mass screening of livestock sera over a certain period can be used to detect emerging or silent disease, chronic or acute infections, effectiveness of vaccines, and duration of specific antibody activity. This information can be used by veterinarians to give advice on the treatment of diseases, vaccine programs, production and reproduction, and culling.

The prevalence of infectious diseases can be monitored on many herds in a geographical area and correlated with epidemiological determinants. A rabies surveillance system annually monitors the occurrence of rabies in wildlife, domestic animals, and humans in the United States (Krebs et al, 1997). The reported cases are a crude indication of the occurrence of the disease and do not indicate the extent of viral infection among wildlife or domestic animals in any region. The cases reported are based only on those cases of rabies that were diagnosed in the laboratory and reported to the Centers for Disease Control and Prevention. Many rabid animals are never observed and thus are untested and undetected. The information is useful for the implementation of vaccination campaigns and control programs. Within broad geographical regions of the United States, rabies infections in terrestrial mammals can be linked to distinct virus variants, which are identified by reaction with panels of monoclonal antibodies or by patterns of nucleotide substitution determined by genetic analysis. This allows monitoring of the spread of virus variants geographically and within and between species.

The provision of a comprehensive animal-health surveillance program that provides an early-warning system for the introduction of new diseases into a country is a function of national animal health regulatory agencies of many countries. In New Zealand, a key component of the surveillance program is a network of Animal Health Laboratories that are situated at regional centers throughout the country and staffed by a team of well-trained veterinary diagnosticians (Sanson and Thornton, 1997). The costs associated with the surveillance are substantial, but so are the benefits. The system is necessary in the event of the introduction of a new disease and the ability to satisfy the export requirements of animals and animal products. The introduction of *S. dublin* into New Zealand cattle herds, for example, would have a substantial impact on the cattle industry and would be a public health concern. With the use of simulation modelling of such an occurrence, the time to diagnosis is a function of the number of farms in the clinical state per week and the probability of diagnosis. The median time to first diagnosis under the current surveillance program regime was 4 weeks under all three epidemic scenarios, when there would have been only one or two infected premises. In contrast, the median time to initial diagnosis under the reduced surveillance scheme varied from 33 weeks under the worst-case scenario to greater than 78 weeks under the least case epidemic scenario. Any reduction in funding allocation of such an activity in countries that are heavily dependent on agricultural exports affects the laboratories' ability to conduct the tests required to make a diagnosis.

In Canada, the Canadian Animal Health Network (or CAHNet) was established in response to requests from WHO to increase animal disease surveillance (Inch, 1997; Kellar and Inch, 1998). The goal is to ensure that animal disease does not impede trade. The network will gather and disseminate information about animal diseases that exist within or beyond the borders of Canada. The network will coordinate federal, provincial, and private efforts with regard to trade-sensitive OIE list B and C diseases that historically have not been the mandate of federal disease surveillance. The network links animal disease surveillance partners in Canada. All Canadians involved in domestic animal production, livestock producers, veterinary practitioners, government veterinarians, veterinary colleges, researchers, exporters, and importers are network members. The surveillance program comprises three broad categories: data gathering, data evaluation, and knowledge communication (Kellar and Inch, 1998). Once the analysis of the data is completed, the information is communicated to partners through a bulletin and other publications such as the *Canadian Veterinary Journal*. The *CAHNet Bulletin* is published regularly on the Internet (http://www.cahnet.org/commun.htm) and in hard copy.

The identification of individual animals is an integral part of any successful disease surveillance program. Being able to trace the origin of an animal examined in the abattoir or to identify animals that have been in contact with animals in an epidemic of disease is vital to the program. In Canada the federal government identified, recorded, and monitored about 95% of calves through the national herd, from farm to slaughter (Inch, 1998a). The identification program was an integral part of the eradication of brucellosis and tuberculosis in cattle in Canada. The Livestock Identification Working Group has the mandate for the identification of all livestock species (Inch, 1998a). Because of major public health concerns over bovine spongiform encephalopathy, most of the identification efforts are now being directed to the beef and dairy cattle industries. Since the early 1990s, the Health of Animals Act in Canada has provided the Governor in Council with the authority for "establishing and governing a national identification system for animals that provides for standards and means of

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identification." For the year 2000, cattle industry representatives have agreed to collaborate with the federal government to establish standards in the areas of tag conformation; control of tag numbering and distribution; premises identification; sites and methods of tag capture; database design, capabilities, integration, and access; and audit and promotion.

The identification database, central or distributed according to the needs of the industry, will reside within the industry's complete control (Inch, 1998a). Each owner will be represented by an individual electronic file that bears his or her address and other details, along with the tag series received. Each service sector site, such as feedlots, auctions, abattoirs, and artificial insemination units, will have a file in the system, carrying identifiers similar to those recorded for individual owners. The system will be configured on the basis of tag, owner, geographical location, or any other parameters recorded. The system will be have the potential of identifying GIS coordinates and a premises code, as a means of facilitating automation and disease control efforts. In a fulminating disease outbreak, the federal government may have to control disease that has spread over many premises across several provinces, but for each instance the tracking process will be the same. The system will have captured where the animal was tagged, and, by reference to all tag series issued to that site, a list of potential contact animals will be obtained.

The surveillance and the study of disease geographically will be enhanced by the use of GIS, which provides the technology to study associations between environmental exposures and the spatial distribution of disease (Vine et al, 1997). A GIS is a powerful computer mapping and analysis technology that allows large quantities of information to be viewed and analyzed within a geographical context.

Genetic Selection for Resistance to Infectious Disease

Because of the persistent difficulties of controlling infectious diseases with the conventional methods described, there is interest in using selective breeding programs to enhance natural resistance. The term *natural disease resistance* refers to the inherent capability of animals to resist disease when exposed to pathogens, without prior exposure or immunization. The ultimate goal of most studies of natural resistance is to breed selectively to increase herd resistance to disease. Some examples of natural resistance to infectious disease include brucellosis and K88+ colibacillosis in pigs in which some strains of pigs are resistant to infection. Poultry breeders have applied successful selective breeding programs to produce stock with increased genetic capability to resist specific diseases. The possibility that cattle could be selected for resistance to mastitis has been a subject of consideration for many years, but little progress has been made. However, there is some evidence for a genetic basis for disease resistance and, in spite of low heritabilities for disease traits, genetic variation for disease incidence is economically important and justifies some consideration in breeding programs.

Genetic improvement leading to disease resistance achieved by both conventional breeding techniques and recently developed techniques in molecular biology may contribute considerably to reduce the costs of infectious disease (Müller and Brem, 1996). The various strategies that provide transgenesis to improve animal health have been discussed and reviewly briefly. The application of gene transfer in livestock depends on the acceptance of this technology by the public as well as the introduction of appropriate laws permitting the use of transgenic animals in animal production.

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CHAPTER 5

Investigation of Disease Outbreaks and Suboptimum Productivity in Herds

CHERYL WALDNER

Food animal veterinarians are sometimes presented with disease outbreaks and unexplained changes in herd productivity. To investigate these outbreaks, the veterinarian must take on the role of medical detective (Schwabe et al, 1977). The resulting field of medical detection has become known as "shoe-leather" epidemiology, and it can be one of the most interesting and challenging aspects of herd medicine. Veterinarians who successfully resolve outbreaks or reverse downward trends in productivity provide a unique and invaluable service to their clients.

Opportunities to investigate herd problems are overlooked sometimes in busy rural practices. The veterinarian may focus too much attention, for example, on addressing the client's concern about the perceived failure of a specific pharmaceutical or vaccine rather than the underlying herd problem (Ribble et al, 1998). Why are opportunities to investigate outbreaks and changes in herd productivity often missed? Some herd owners may be reluctant to admit that they are having a serious herd problem. In other cases the herd owner may not recognize the severity of slowly escalating herd losses, particularly during busy and stressful times such as calving. Also, many herd owners do not recognize the potential of their local veterinarian to assist in diagnosing and resolving herd-level productivity problems.

By recognizing and pursuing opportunities to examine disease and productivity losses, practitioners cannot only help their clients with the current problem but also can promote the importance of veterinary herd health services. Significant herd-level problems are often identified from the history of a single animal presented to a clinic for examination and treatment. At other times, the veterinarian will detect changing patterns in drug sales or individual animal problems in a particular herd. Opportunities to follow up the problem at the herd level should not be dismissed without some consideration. A successful herd outbreak investigation can often be the first step in a long-term production and health management program in a herd. After working through a disease problem many herd owners recognize the benefits of good herd record keeping and the implementation of health management protocols.

The depth of the investigation should be justified by the economic importance of the herd problem (Radostits et al, 2000). An adequate and thorough herd investigation requires a great deal of time and can be expensive. Intensive investigations are most necessary when the determinants of disease are not well understood or several determinants are interacting to increase the risk of disease in a herd, and additional information is necessary to plan appropriate control measures.

The diagnosis of herd-level problems requires many of the same skills used in the examination and treatment of individual animals. These include a systematic approach to history taking, physical examination, and pathology as well as adequate knowledge of nutrition, microbiology, toxicology, immunology, genetics, and animal behavior. In addition, the investigator must be a skilled observer and have a good understanding of the livestock industry, herd management, and the basic tools of epidemiology (see Chapter 2). Industry knowledge, experience, and preparation are necessary to first differentiate correctly the normal and unusual patterns of herd health and productivity and then identify the risk factors associated with the abnormalities.

No single protocol can be applied to investigate and resolve all herd problems. The variety of concerns investigated is too large. There are, however, some basic principles that are useful for both the investigation of epidemic disease outbreaks and the examination of suboptimal herd productivity. These basic principles, with minor variations, have been reported in many sources (Schwabe et al, 1977; Kahrs, 1978; Lessard and Perry, 1988; Ribble et al, 1998) and are presented in this chapter.

OBJECTIVES

The broad objectives of the clinician are to halt the progress of disease, determine the reasons for the outbreak, institute corrective measures, and recommend procedures to reduce the risk of future outbreaks (Martin et al, 1987). These objectives can be achieved most consistently by differentiating the characteristics of affected and unaffected animals within the study population and by observing, recording, and analyzing the distribution of the disease with respect to time, place, and other potential exposure factors and environmental influences (Kahrs, 1978).

Risk factors are characteristics of the host, agent, or environment associated with an increase in the probability of disease or reduced performance. Risk factors can be manipulated to resolve the outbreak or improve herd production and profitability. For example, some risk factors for impaired fertility in beef cattle include body condition at calving, bull performance, reproductive tract infections, and nutritional deficiencies (Wikse, 1988). The risk factors over which management has control and that can be altered to affect disease rates or production levels are sometimes referred to as *key determinants* (Wikse et al, 1992; Sanderson and Christmas, 1997). Nutrition is an important key determinant of reproduction in beef cattle.

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PROCEDURES FOR INVESTIGATING DISEASE OUTBREAKS

To achieve the objectives of a disease investigation in a herd, the investigator must systematically work through the following questions (W5): what (and how much)? who? when? where? and why (Gregg, 1996; Ribble et al, 1998)?

The herd owner invites the clinician to the farm to stop the problem, not just describe it. From the time of initial contact, an initial hypothesis regarding the cause of the outbreak will begin to develop. When appropriate, action should be taken to stop the epidemic based on the working hypothesis even before the investigation is complete. For example, in cases in which exposure to a toxin is suspected, the animals should be moved or alternative food or water sources provided to minimize any additional exposure. The veterinarian and herd owner should work together to minimize further losses as soon as possible.

Define the Problem (What?)

The first and most critical task early in the investigation is to *clearly define the problem* (Ribble et al, 1998). This is often one of the most difficult parts of the investigation. The initial complaint can encompass many different types of health and production issues. The investigator might be presented with clinical disease, subclinical disease, impaired performance, negative trends in productivity, inadequate profitability, or potential public health concerns related to food safety or environmental issues. Establishing a working definition of the problem as early as possible creates a focus or starting point. This definition will be reworked continually as the investigation progresses and more information becomes available.

An outbreak of a single disease must be differentiated from the simultaneous occurrence of many unrelated conditions. Case definition becomes very important early in the investigation. A case as an animal, group of animals, or herd having the characteristics associated with a disease or a deviation from productivity targets (Lessard, 1998). The defining characteristics are selected by the investigator and can include attributes such as clinical signs, test results, or individual traits such as age, breed, sex, or other distinguishing features. The simplest and most objective criteria are usually the best for the working case definition, particularly if there is more than one person participating in the investigation (Gregg, 1996). A simple, easily recognized and applied definition facilitates the consistent reporting of cases by the herd owner, other farm workers, and cooperating veterinarians.

Most field investigators compare diseased animals with animals not affected to identify exposures that may have contributed to the outbreak. The potential for inclusion of animals with unrelated conditions can be minimized by defining the problem as precisely as possible. This definition is critical when comparing cases with noncases to determine the importance of potential risk factors for disease. The inclusion of unrelated cases can result in errors in recognizing factors that might have contributed to the outbreak (Lessard, 1988). Case definition can be particularly challenging in retrospective field investigations. For example, one of the challenges to investigating a midgestation abortion storm, in a beef herd that had not been pregnancy tested before the outbreak, was differentiating between cows that aborted and those that failed to conceive (Waldner et al, 1999). Low pregnancy percentages for beef herds and late abortions can be associated with very different risk factors.

Establish the Existence of an Outbreak or Suboptimal Herd Production (How Much?)

Once a working case definition is established, the owner's complaint and the existence of an outbreak can be verified. To determine if the outbreak is real, the productivity and disease frequency in the herd can be measured and compared with published or historical expectations or to the performance of other neighboring herds with similar management. Some investigators have suggested that a change in disease risk, mortality, or production in excess of 2 standard deviations (SDs) from the mean or expected level can be considered an outbreak and should be investigated (Martin et al, 1987; Lessard, 1988).

The definitions of *outbreaks* and *epidemic* often overlap. As with the term *epidemic*, reference to an outbreak suggests both an unexpected problem and that an expected threshold for that problem has been exceeded (Toma et al, 1999). An *outbreak* as the occurrence of events (disease, impaired productivity, or both) in a population, clustered in time and space, the incidence of which is markedly in excess of the expected incidence (Lessard, 1988). Because the expected incidence of different diseases varies, an extensive outbreak investigation could be triggered potentially for as little as one case. One animal with evidence of a reportable foreign disease would trigger a large regulatory investigation.

Most outbreaks are identified and reported by the herd owner. The determination of what is presented to the veterinarian is dependent on the individual owner's threshold of concern (Ribble et al, 1998). The extent of the underlying problem can vary dramatically among different herd owners. Large problems can go unreported, whereas disease losses with accepted or expected rates can be alarming for some herd owners (Wikse et al, 1992). The expenditure of time and resources on the investigation of epidemics that do not exist can be minimized by first confirming the existence of an actual outbreak (Lessard, 1988). However, convincing the concerned farmer that there is "no problem" can be extremely difficult and often requires a great deal of patience and persistence on the part of the veterinarian. Seemingly frivolous concerns should never be dismissed without adequate information.

Orient the Problem: Characteristics of the Animals Affected, Time, and Place

Given that there is sufficient evidence to proceed with an investigation, the next steps are to answer the questions of which animals or groups are affected (*who*), *when* did they became affected, and *where* the affected animals were and are located (Radostits et al, 2000). This information is used to group animals within the investigation herd using these three factors: *host characteristics*, such as age, sex, and breed; *time*, particularly the date of onset; and *place or location* of affected animals or groups of animals (Smith, 1995).

Define the Groups of Animals Affected Within the Herd (Who?)

The amount of information available varies greatly among herds, depending on management, animal identification, and record-keeping practices. The clinician should collect all available information on the diseased animals, including identifying brands, tags (plastic and metal), or tattoos; age, sex, breed, and color; use; origin (purchased or born on farm); sire and dam; feed and water source; pastured, yarded, or housed; stage of reproductive cycle or gestation; lactation status; parity; clinical, pathological, or laboratory signs; processing, vaccination, and treatment history; and

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status of exposure to other potential risk factors (Lessard, 1988). A detailed individual animal listing or inventory is very useful but often not readily available.

Where herds are managed in distinct groups, much of this information can be collected and entered at the group level rather than individual animal. When collecting information about groups of animals, the investigator should ask if there are any exceptions. For example, data obtained for a group of yearling heifers in a cow-calf herd may not reflect the two older cows kept in the group to calm the younger animals. The information collected should include observations on unaffected as well as affected animals within the herd (Lessard, 1988). In some cases, information on neighboring herds can also be very useful. Have other herds within the area experienced similar problems recently? Information can be collected through phone interviews, written questionnaires, herd visits, and examination of the herd inventory and production records.

Orient the Problem in Time (When?)

Understanding the time sequence or temporal pattern of disease provides many important clues about the origin of disease in the herd (Lessard, 1988). A well-constructed graph (or *epidemic curve*) can help describe the pattern of disease. Epidemic curves have been used to describe the pattern of a number of important diseases, including the onset of shipping fever in feedlot cattle (Fig. 5-1). The clinician should consider whether this is a new or a long-standing problem in the herd. Have the numbers of new cases increased, stabilized, or peaked and started to decrease? The time of onset of each case (x-axis) should be plotted in appropriate intervals against the number of cases recognized at each time interval (y-axis). The best time interval to summarize the data varies with the accuracy of the records and intensity of the outbreak and may be hours, days, weeks, or even months. Other critical factors, including recent additions and changes in herd management, feeding practices, or the environment, when indicated on the epidemic curve, help the clinician visualize the time sequence of events.

From the epidemic curve, some inferences can be made about whether the problem is endemic in the herd, represents epidemic disease, or is a sporadic occurrence. An *endemic* disease occurs at a consistent level in the herd with only minor fluctuations over time (Fig. 5-2). The percentage of animals affected may be very low or include most of the herd. *Epidemic* is a relative term used to describe disease within a given time interval that is clearly above its expected rate of occurrence. A disease is *sporadic* if it occurs rarely and follows no regular pattern (Smith, 1991) (Fig. 5-3).

Epidemic curves can be used to identify periods of high exposure risk (Lessard, 1988). The pattern of disease can suggest whether the problem resulted from a single point source exposure or whether the occurrence of cases is better described by an infectious agent moving from one animal to the

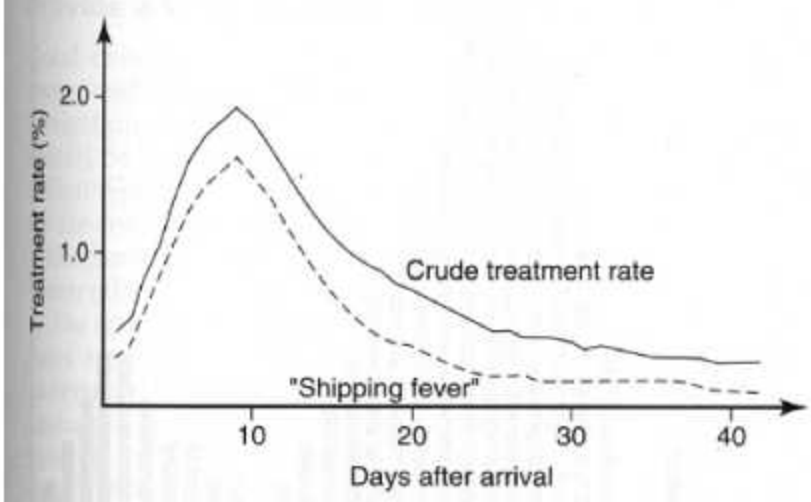

FIG. 5-1 Summary epidemic curves of crude treatment rate and "shipping fever" treatment rate for 106 pens of feedlot cattle. Alberta feedlot disease pattern study from 1983 to 1984 (From Kelly AP: *Disease patterns in feedlot cattle*, MSc thesis, Saskatoon, Saskatchewan, 1984, Department of Herd Medicine and Theriogenology, University of Saskatchewan.)

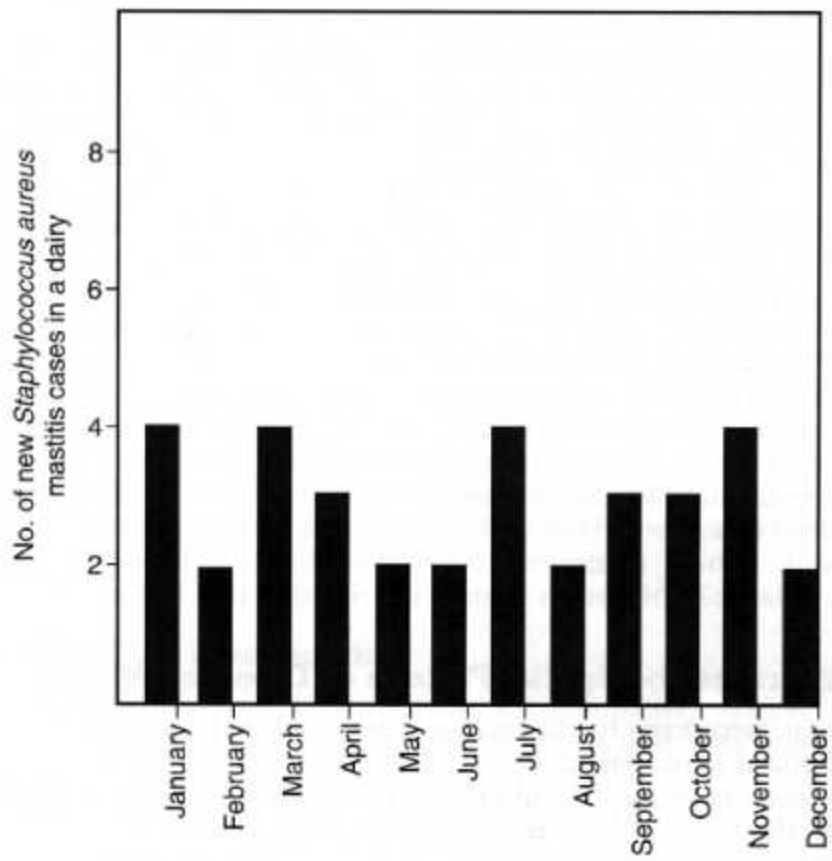

FIG. 5-2 Epidemic curve illustrating an endemic mastitis problem in a dairy herd.

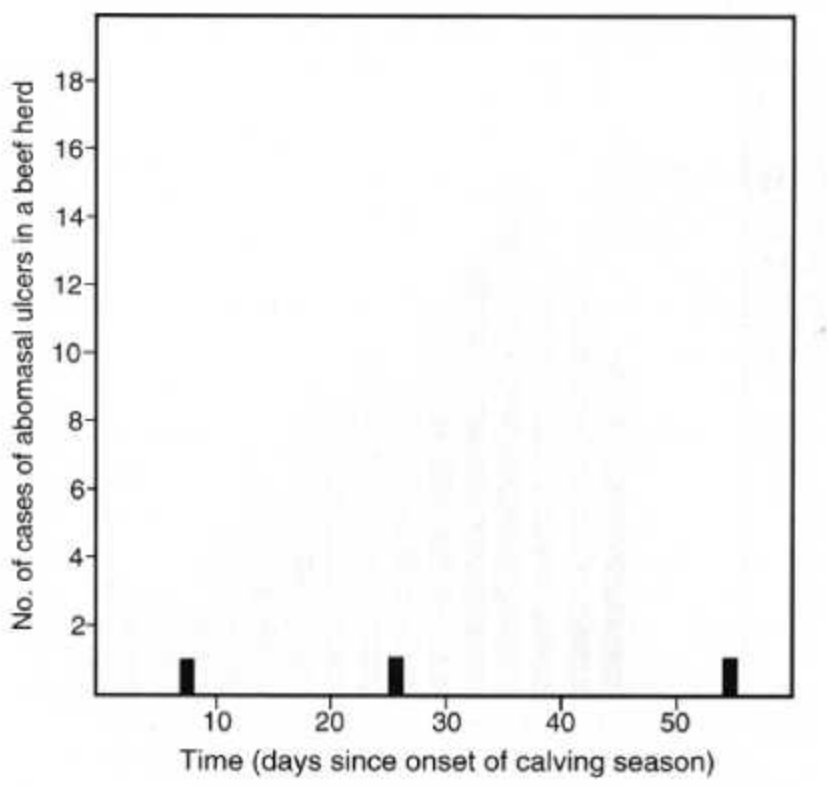

FIG. 5-3 Epidemic curve illustrating a sporadic disease problem in a cow-calf herd.

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next. The slope of the curve suggests whether the whole group was exposed at one time or if there were multiple exposures over a certain period. For example, an epidemic curve that has a relatively short time span of new cases and a dramatic upward slope is consistent with a *point source* exposure to the causative agent (Gregg, 1996) (Fig. 5-4).

A less steep upward slope followed by a more defined down slope and often one or more additional peaks can suggest a *propagated* agent (Gregg, 1996) (Fig. 5-5). The pattern of the curve may suggest an infectious agent moving between animals and groups of animals. The shape of the curve reflects the incubation pattern from infection to the time the animal becomes contagious and the timing and number of opportunities for transmission (Radostits et al, 2000). The incubation period for an infectious disease can often be estimated from analysis of the pattern of clinical onset data (Lessard, 1988).

Where the information is available, the location and identification of the first case *(index case)* can provide valuable epidemiological clues about the source of infection in the group. Identification of the index case can be extremely important in cases where an exotic or reportable disease is diagnosed. In these cases an intensive "trace back" will be initiated by the investigating regulatory agency to determine the origin of the first sick animal and potential contacts with other herds. Determining the amount of time from when the animals were first observed sick until they were found dead can also be very useful, when this information is available. Where treatment records are limited, however, the available information is often restricted to the date of death.

Examine the Spatial Pattern of Disease (Where?)

It is necessary to determine where affected animals were housed and pastured in relation to unaffected animals (Lessard, 1988). This often requires a detailed sketch or map of the farm and surrounding area. The clinician must also understand if and how the herd was organized into separate management groups. One common example is the division of dairy heifers into separate groups and facilities based on age and reproductive status. Information on the occurrence and timing of movement of groups of animals between different housing facilities or pastures is important, as is any information on the movement of animals between different management groups. The location of management groups in relation to neighboring herds and the potential frequency of contact with neighboring herds should also be examined.

A simple way to describe location is by preparing a *point map* of the farm (Thrusfield, 1995). A sketch of housing facilities, corrals, pastures (including details of cross fencing), feeding facilities, and watering sources should be prepared. Any potential areas of concern including chemical storage areas, garbage dumps, or industrial facilities should be noted (Lessard, 1988). The location of each management group at the time of the outbreak can be overlaid on the map and the location of individual cases. This map can be used as a visual aid for detecting patterns of disease and developing hypotheses about the location of exposure. A series of maps showing animal movements and pattern of disease over time can also be used.

Summarize and Analyze the Herd Data (Why?)

Data to answer the previous questions (what, how much, who, when, and where) are collected from many different potential sources, including interviews, questionnaires, herd visits, laboratory reports, and herd production and health records. The analysis begins with organizing and summarizing the data for the entire herd. The next step is to quantitatively describe the breed and age structure of the population, the physical examination, and laboratory results and then characterize the problem using descriptive statistics. Herd average morbidity, mortality, and productivity level should be calculated and then repeated for groups of individual animals identified within the herd. Hypotheses are made about the key determinants of disease or low productivity in the herd by comparing the risk of exposure between groups of diseased and nondiseased animals or, alternatively, by comparing the risk of disease in groups of exposed and nonexposed animals. The methods used to measure disease, the appropriate tools to measure the association between risk factors and disease, and finally the application and in-

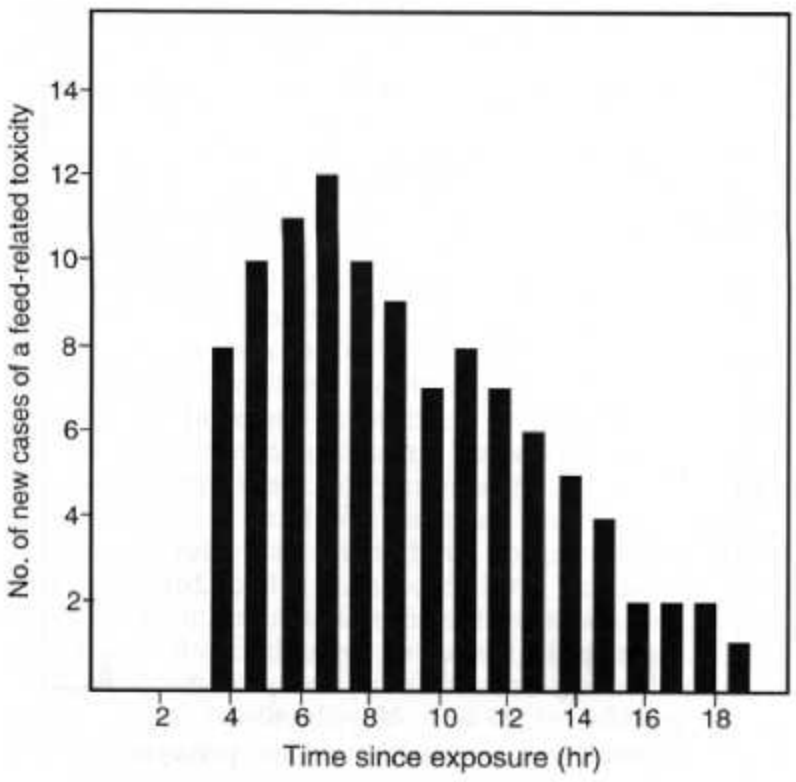

FIG. 5-4 Epidemic curve illustrating a point source disease outbreak in a feedlot.

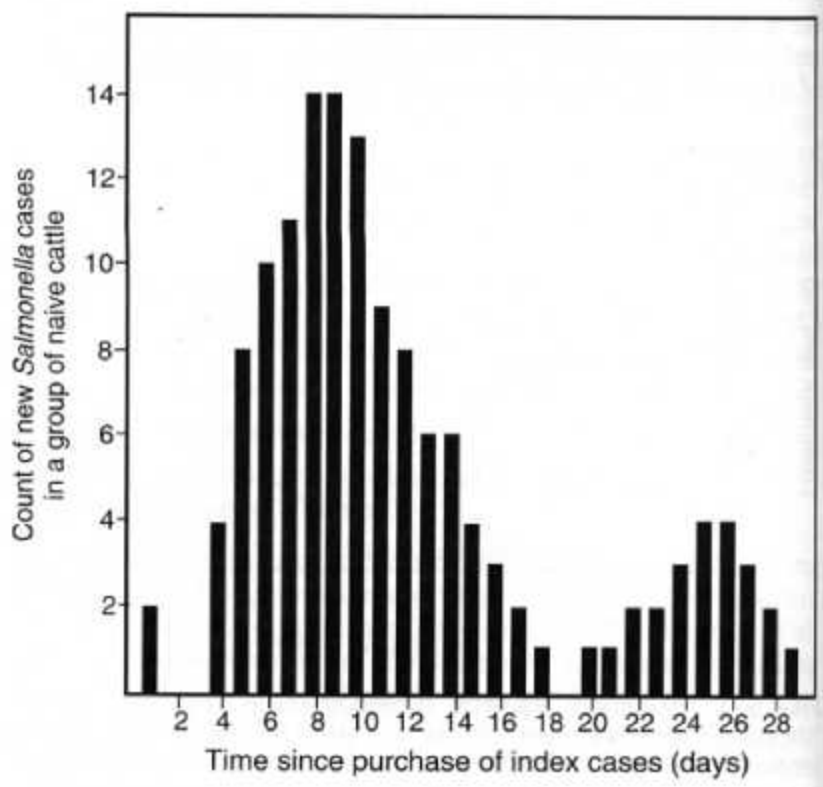

FIG. 5-5 Epidemic curve illustrating a propagated infectious disease epidemic in a cow-calf herd.

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terpretation of statistical tests have been covered briefly in Chapter 2. Measures of association are reviewed near the end of this chapter.

The results of the initial analysis often suggest factors that are determinants of disease risk or productivity problems in the herd. Methods based on *Mill's canons* for inductive reasoning can be used to identify and rank the importance of factors contributing to the outbreak (Martin et al, 1987). One strategy is to identify the factors that are common to most or all diseased animals and evaluate whether these factors may have contributed to disease ("method of agreement"). Were most or all of the affected animals of the same breed, age, or sex? Were they pastured together, or were they given the same ration?

The second and perhaps most successfully used investigation technique is the "method of difference." Many factors are examined to determine what is different about the animals that are diseased. Initially, rates of disease can be compared across different age, breed, or management groups within the herd. This method is frequently also used to interpret laboratory results. The diseased or affected animals should have a significantly higher frequency of positive test results than their unaffected herd mates if the test reflects an important risk factor for the disease.

When the conditions in which disease occurs are similar to those in which disease does not occur, with the exception of one factor (or group of factors), the presence or absence of this factor (or group of factors) may increase the risk of the disease. Variation in the occurrence of disease with the intensity or frequency of the suspected exposure factor ("method of concomitant variation") can provide additional evidence that the factor may be an important risk factor for disease. This principle is often applied when a nutritional or toxicological problem is suspected. The animals that were most exposed to some potential toxin should, in most situations, exhibit more profound clinical signs than those exposed to less of the same substance.

The comparisons just mentioned form the initial foundation for the answer to the final question: *why did the outbreak occur?* Sometimes these comparisons identify one or more key determinants for the disease outbreak or herd productivity problem. Other times this process targets specific questions that can be addressed by obtaining additional information from the herd owner or through focused laboratory testing. Several rounds of collection of additional data and analyses can be required with complex herd problems.

Provide a Written Report to the Herd Owner

Good communication must be maintained with the herd owner and other consulting veterinarians throughout the investigation. Preliminary reports summarizing initial findings should be issued within a few weeks of the initial herd visit. A final report can be issued later when all laboratory analyses are completed. A professional, clearly written document is necessary to communicate effectively the results and recommendations coming from the investigation.

The report must be written for the intended audience. Most reports are prepared for the herd owner. To make the report understandable to the intended audience, it must be well organized, concise, and explain the findings and recommendations of the study without excessive scientific or industry-specific terminology (Gardner, 1988; Lessard, 1988). The report should contain the following sections (Gardner, 1988; Ribble et al, 1998):

- Background to the investigation and the initial complaint
- Objectives
- Legal land location of the herd
- History
- Methodology
- Description of the facility and herd management
- Results of clinical and pathological examinations
- Laboratory results
- Summary of data analysis
- Discussion of results and diagnosis
- Assessment of financial impact of the problem
- Recommendations
- Appendices, including copies of relevant laboratory reports

Tables and graphs should be used to summarize results when possible. The best graphs convey no more than one idea (Altman, 1991). Elaborate special effects can clutter the presentation and make the data more difficult to understand. The recommendations should be presented with sufficient detail to avoid confusion (Gardner, 1988). Both short- and long-term recommendations may be necessary. The potential costs and benefits should be explained to the herd owner.

Occasionally herd-level problems involve liability issues that eventually may end up in litigation. Examples of potential legal cases include herd losses from feed or water contaminated with toxins, purchased replacement stock that are carriers for disease, and adverse reactions to pharmaceuticals. The written report should contain sufficient information so that the veterinarian can explain and defend the investigation results as many as 10 or more years after the original problem. Unusual or unique herd investigations should also be considered for peer-reviewed scientific publication.

Follow-Up Investigation

Relatively few complex problems are completely resolved with a single report. Many investigations are done retrospectively with insufficient information to reach definitive conclusions. In these cases, protracted herd health and productivity monitoring and occasionally planned follow-up studies are required to address outstanding questions. Structured observational studies can be used to define the importance of suspected risk factors. Study types include cohort, case-control, and cross-sectional designs (Smith, 1991; Thrusfield, 1995). Where there is a rapid solution to the problem and control measures can be introduced, follow-up field studies may be required to determine if the control measures are effective. In some cases, a planned randomized clinical trial is the best way to determine the success of specific recommendations. The appropriate intensity of the follow-up studies will be determined by the importance of the problem to the individual producer or to the industry in general. Planned field studies require a large amount of time and can be very expensive (Perry, 1988). Consultation with an epidemiologist before initiating a field study helps ensure the study design meets the intended objectives.

DATA GATHERING: INITIAL CONTACT, THE HERD VISIT, AND COLLECTION OF SAMPLES

The basic process of defining the problem, orienting the problem by animal, time, and space, and analyzing the data is common to all outbreak investigations. The steps often overlap in time and parts of the process may have to be repeated to resolve the problem successfully. The practice of outbreak investigation requires preparation, organization, and communication skills from the initial contact with the herd owner through implementation of the recommendations in the final report. Some practical suggestions for a structured and consistent approach to field investigations

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are presented below; however, no one approach applies to all situations.

Initial Contact and Preparation for the Herd Visit

Most herd investigations begin with a phone conversation, from questions raised over the counter at the clinic or during some other routine procedure. Herd owners should be encouraged to *describe the problems in their own words*. Good listening skills are very important, and questions should be asked only for clarification. The information will be biased if the interviewer excessively directs or monopolizes the conversation.

Herd problems should not be diagnosed by phone or "over the counter." Veterinarians should be reluctant to offer comment on economically significant herd-level problems without at least one herd visit. Although many herd owners can describe the problem well, incomplete or misleading secondhand information could result in inappropriate recommendations and leave the veterinarian potentially liable for the well-intentioned "free advice" (Ribble et al, 1998).

If this is the first visit to the farm, the investigator needs to collect some background information including complete name and address of the herd owner, the legal land description of the farm, and all important phone numbers. Have other veterinarians been working with the herd? If so, find out who and when. Previous examination or laboratory testing reports from the herd should be retrieved, if possible, and copied to save time during the herd visit.

Communication and preparation before the herd visit can optimize the limited time available on the farm. The client should be encouraged to gather all potentially relevant herd records before the planned visit. These may include herd record books, sales receipts, calendars, invoices for purchased feed, and other data depending on the type of operation. Some clinicians suggest having the client fill out a preliminary questionnaire covering basic herd background information. The initial questionnaire should include information such as the herd inventory and recent changes, breed and age distribution of the herd, management groupings, and feeding and vaccination practices. This background information will allow better planning of what and how many animals need to be examined and the number and type of appropriate laboratory samples.

The visit should be arranged so that everyone who works with the animals can be present at some point during the day. In addition to the herd owner, the clinician can obtain important information from other family members and farm workers. Also, if possible, the veterinarian should arrange to examine the herd in their "home pen" or usual location before they are disturbed and confined for detailed examination. It is often easier for a "stranger" to walk or ride through and examine the animals when the animals are actively grazing or just after they have been fed. The clinician can observe the group with minimal disturbance to the animals. This is an excellent opportunity to make observations of both animal behavior and herd management. If there are no nearby handling facilities, a second visit may have to be scheduled during some routine management procedure, such as pregnancy testing, vaccination, or branding, to facilitate detailed examination. More than one herd visit might be necessary to make both the necessary herd- and individual-level observations.

A "crude" working case definition can be constructed from the information provided during the initial contact. The investigator can save time, particularly for unusual or complex problems, by briefly reviewing the current literature on the known risk factors for the problem before the herd visit. A *path model* is a diagram summarizing the current understanding of the risk factors for the disease or productivity problem under investigation. Several good examples including path models for neonatal mortality in beef herds (Wikse et al, 1992), impaired fertility in beef cattle (Wikse, 1988), and factors affecting weaning weights (Sanderson and Christmas, 1997) have been published.

In addition to listing risk factors for the disease, the path model depicts the known information about the interrelationship between risk factors and their effects (Hancock and Wikse, 1988). Among other things, these diagrams help communicate to the herd owner that herd problems usually have more than one cause, that many areas of management may be deficient, and that infectious agents are usually only one part of the problem (Wikse et al, 1992). This review process also serves as a listing of the most likely risk factors. A complete investigation that evaluates the extent of involvement of all probable risk factors in the herd is necessary to provide sound recommendations for resolving the outbreak. By taking the time to review the potential risk factors for disease before the herd visit, the chance that either some area of herd management or the collection of important samples is overlooked will be decreased.

Preparation for the visit is important. In many cases there will be only one opportunity to examine the animals closely and to collect samples. An animal health technician can help organize sample collection and ensure everything is properly labeled and packaged for transport. The proper sample collection equipment should be packed in sufficient quantity to allow for surprises and accidents during the herd visit. The laboratory should be contacted before the visit (several days if possible) to verify the manner of sample collection, quantity of sample, type of container to be used, and packaging and transportation recommendations. Many private laboratories have sample collection containers and transportation packages that they will provide on request to their clients as part of their service fee or for a small additional charge.

The practice of herd investigation differs in some ways from routine ambulatory practice. A list of useful equipment not always carried for individual animal calls might include notebooks and pens for logging visit notes and samples collected; a calculator and possibly a laptop computer and printer; a good camera, pocket cassette recorder or video camera; a measuring tape, weigh tape, and calf weigh scale; ear tags and applicators; livestock markers; a current county or municipal district map; and a portable photocopier. A *photocopier* can save substantial time spent abstracting records and minimize the number of errors. The laptop computer and printer are also useful. Some veterinarians have expressed concern about the difficulties in getting paid full value for time at home spent entering records and doing records and nutritional analysis. Doing some of this work on farm and together with the herd owner can increase their appreciation for the time and effort required to complete the analysis.

Herd Visit

The examination of the herd includes collection of additional history, clinical examination of individual animals from the herd, necropsy examination of dead or euthanatized animals, observation of herd management and examination of the environment, collection of samples for laboratory examination, and examination of the herd records. This series of steps is a general guideline only, and the steps often overlap each other. This data-gathering process is followed by descriptive and analytical epidemiological evaluation of

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the results (Radostits et al, 2000). The objective of the herd visit is to determine first how the affected or diseased animals differ from those that are not affected, and then which of the factors that differs among these groups can be altered by intervention to decrease the risk of disease. The unique characteristics of the group of animals that is affected become a focus of the examination. Nutrition, management, and the environment are examined in relation to this group of animals.

Detailed written notes of all observations are important for constructing a meaningful and accurate report for the herd owner. Few things destroy a clinician's credibility faster with a herd owner than making a substantial mistake in describing the herd owner's operation. *All records should be in ink, dated, and signed.* A *camera* and *video camera* can be important aids in documenting observations. Pictures are a valuable memory aid and a great tool for client education and presentations to producer groups. If the case potentially involves litigation, date (and time stamp) the photos or video if possible. A record should be maintained of where and when the pictures were taken and a detailed voice narration on the video should include a description of what was observed. If a digital camera is used, the admissibility of the pictures as evidence should be discussed with a legal expert in the local area.

Cameras can be useful, particularly for recording somewhat subjective observations such as body condition score (BCS) and farm hygiene. Pictures from two different dates can be compared to monitor change over time. When trying to show the relative size of an object in a photograph, include a marked standard reference in the picture (e.g., a ruler, meter stick, or person of a known height). If individual animal identification is important, try to include the ear tag and brand, if applicable, in the photo. If it is impossible to have everything in the same picture, consider having someone hold or place a small sign or card in the picture with the necessary information. Video cameras are an excellent tool for recording behavioral or postural abnormalities and, sometimes, unusual sounds.

History. Always start from the beginning. The information was probably discussed during the initial contact, but this is an important opportunity to verify the phone conversation notes. Find a quiet and comfortable place such as the kitchen table or the office and have the herd owners restate the presenting complaint in their own words. The herd owner should be encouraged to present the events in chronological order if possible. The time sequence or time between events is crucial. Any unclear references should be clarified. The interviewer must avoid interrupting unnecessarily and "jumping to conclusions" during questioning (Ribble et al, 1998).

A list of questions prepared for the problem under investigation can help ensure nothing is overlooked during the interview—particularly for those who are gaining experience in this field. Although strict adherence to standardized questionnaires is necessary for most observational research designs, this same strict adherence to a prepared questionnaire can hinder the outbreak investigation process. No standard questionnaire fits every situation, and attempts to follow a preformatted series of questions interfere with the chronological order of the story (Ribble et al, 1998). Preliminary discussions with the herd owner and occasionally a simple previsit questionnaire can be used to prepare a list of required information to be obtained during the interview. This list can be used as a check sheet after the farmer has told his or her story to fill in some of the areas not covered in the initial contacts.

History-taking is an art and a science. Interview questions should be presented carefully. Below are several guidelines for collecting both oral and written information from the herd owner (Armstrong et al, 1994):

- "Open-ended questions" should be used when possible.
- Scientific language and industry jargon should be avoided.
- Ask for only one piece of information at a time.
- Avoid using double negatives in questions because they are confusing.
- Be cautious of "emotionally loaded" or "leading" questions that would suggest one answer is better than another.
- Questions should contain unambiguous, clear time references.

If questions are not presented carefully, the herd owner will in many cases be tempted to give the "correct answer" or the answer he or she thinks is more "socially acceptable" and not what actually happened. For example, when trying to evaluate the effectiveness of a particular treatment, written records or firsthand observation of actual treatments supplemented by a determination of the total amount of drug used often is more revealing than questions about what dose and frequency of administration was used. The quick and easy answer to a question about treatment protocol might be the information written on the side of the bottle—whether or not this was the actual amount given.

The use of "aids to recall" can improve substantially the accuracy of information obtained in the interview (Armstrong et al, 1994). Encourage the herd owner to verify dates and numbers using herd records or the kitchen calendar (Ribble et al, 1998). Often people have difficulty remembering brand names of the specific drug, vaccine, electrolyte, milk replacers, or mineral mix they used. Some props to help stimulate recall might include a list of drug names or a binder with examples of labels or packaging.

Much of the interview should be focused on collecting the owner's observations and not interpretations. First, ask the herd owner to describe what has happened in as much detail as possible (Radostits et al, 2000). However, after the required information has been recorded, give the herd owner opportunity to present his or her interpretation of events. He or she may present a possible cause or connection the clinician did not consider.

The history should include information on the herd owner, the history of the operation, and the type and number of animals. In addition to basic name and address information on the herd owner, inquire about off-farm jobs because this could be a potential source of risk in some herds. For example, the person who works in another herd or at an auction market could bring disease back into his or her own herd. The herd owner, any employees, and the families should also be questioned tactfully about concurrent illnesses if zoonotic disease or simultaneous exposures to toxins are potential threats (Ribble et al, 1998). This must be done cautiously so as not to alarm anyone unnecessarily.

The specific questions asked vary with the species, type of management, and type of problem; however, some general areas should be considered in all types of investigations. The disease history should include the following:

- Information on the present disease or productivity problem, including chronology, severity, and duration
- Estimates of the morbidity or treatment rates, case fatality, and population mortality rates
- Prior treatment; any prophylactic or control measures attempted
- Potential for exposure through introductions to the herd
- Any recent transportation of animals or transient introductions to the herd
- An assessment of herd culling practices.

The management history should include an assessment of nutrition quantity and quality, a record of recent changes

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in diet, any supplements used, and the availability and quality of drinking water. Other factors that must be discussed include reproductive management, past and present reproductive performance, and the breeding history of the herd (i.e., in-breeding, line breeding, cross-breeding programs). The vaccination and parasite control programs should be recorded. Many other general management factors, including the adequacy of hygiene, ventilation, drainage, feeding and watering equipment, opportunity for exercise and other equipment maintenance (milking machine maintenance), can be important. As climatic factors can be associated with many types of disease, local climatic information should be obtained first from the herd owner and verified, if necessary, with detailed records from area meteorological stations.

Clinical examination of individual animals from the herd. In many outbreak investigations, it is often not possible to confine and examine individually every animal in the herd. The distant visual examination of different groups in the herd during feeding or grazing is a valuable tool that should not be overlooked or minimized. The visual examination from a distance has been described and is outlined here (Radostits et al, 2000; Wilson, 1992). Both general observations of the group and individual observations should be recorded. Data should include identification, breed, color, sex, and approximate age where possible for individual animals showing notable clinical signs. If individual animal notations are not possible, count the number of animals in the group showing specific signs. The total number of animals and location of the group should also be included in the field notes.

The *visual examination* should include an assessment of the following:

- Behavior, mental status, temperament, and exercise tolerance
- Degree of crowding, dominance, and aggression problems within the group, and the access to and availability of bedding, food, and water
- Voice, respiration rate and character, coughing, and unusual noises or discharges
- Appetite, mastication, and swallowing; abdominal shape or contour (bloated, gaunt)
- Defecation (frequency, consistency, straining) and urination
- Reproductive status, signs of estrus or mounting activity, discharges from the reproductive tract, maternal behavior, udder conformation, and lactation status
- Posture, gait, and progression of movement
- Body weight and condition score; relative frame size and conformation
- Skin and hair coat (health and cleanliness)

Body condition scoring is an extremely useful technique that has been applied successfully to dairy and beef cattle, horses, and sheep as well as other species. Body condition is affected by energy intake, environmental demands, lactation demands, and parasitism. Body condition scoring can be done visually from a short distance where cattle cannot be confined to permit palpation. Visual appraisal is comparable to palpation except when cattle have long hair (Wikse, 1988).

Other clues to the nutritional status of the herd can be found during observation of the group. The amount, consistency, and appearance of fecal material can verify diet composition and provide information on recent changes or accidental ingestions. Fecal consistency can provide information on the amount of dry hay relative to silage, green grass, or concentrate. Fecal content can also reflect recent grain overload or exposure to environmental toxins such as crude oil spills.

Several types of herd problems may be difficult to detect and quantify if the animals are closely confined. A potential herd lameness problem is best initially assessed through observation of the group. Observation of group behavior can also be an important supplement to the investigation of herd reproductive problems. Suboptimal reproductive performance sometimes can be associated with lameness because of inhibited mounting activity and expression of estrus. Bull libido is not assessed as part of routine breeding soundness examination but can be informally assessed in beef herds by observing bull activity on pasture during the early part of the season. Timing of the observations is important. Early morning and evening visits are often the most productive. If a problem is suspected, a more formal service capacity test can be applied (Barth, 1997).

The *detailed examination* of individual animals has been well documented in other textbooks and is not extensively reviewed here. Each animal can be examined individually if warranted by the severity of the problem or if the examination can be combined with other routine processing activities. If this approach is not practical, subsets of severely affected, moderate or mildly affected, and not apparently affected animals from the herd can be examined. Examining the "normal" animals first should minimize the potential for transmitting disease within the herd. There are no specific guidelines for how many animals should be examined; however, a minimum of 12 (8 affected [4 severe and 4 mild] and 4 normal animals) are suggested. Targeting the first few animals that became sick and all recent additions to the herd has also been suggested (Martin et al, 1987).

If all animals are examined individually, a complete herd inventory can be compiled including identification, breed, sex, and approximate age. If the animals are not identified individually, some form of permanent individual identification such as ear tags can be placed during the examination or routine processing. Also, the reproductive status of the herd and BCS the animals should be recorded if possible. If bred cows are not pregnancy tested, this should be done as soon as practical. If the complaint involves reproductive failure, breeding soundness examinations should also be done on any bulls. This individual animal listing and record of reproductive status is particularly important if the problem could require monitoring over time. This inventory information provides an important baseline for further study in the herd.

Necropsy examination. A detailed guide on necropsy techniques for food-producing animals is available (Andrews, 1986). Detailed instructions for necropsy examination are not presented, but some general concepts applicable to multiple examinations and outbreak investigations are included. Necropsy information is particularly important for improving the case definition where clinical signs are vague and nonspecific. *All* available animals that have died should be examined whenever possible. One or two cases from a major disease outbreak might not be representative of the underlying problem. Where the value of individual animals are low, the herd owner might also be willing to sacrifice a small number of affected animals for a complete necropsy examination. If the value of individual animals is high, the herd owner might consent to the euthanasia of one or two chronically diseased animals where the prognosis for recovery is poor.

The investigation of abortion outbreaks and the laboratory examination of the fetus and placenta deserve special note. The approximate gestation age of the fetus should be estimated. The time of loss can be an important clue for infectious etiological agents. Tables associating crown-rump length and gestation age have been published for cattle and

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sheep (Kirkbride, 1986). Few causes of abortions have distinctive gross pathology, making laboratory examination necessary in almost all cases. Where possible, submission of the entire fetus and placenta to the laboratory is preferred to examination in the field. Fetal postmortem diagnoses are made more difficult because many fetuses are retained *in utero* after death and are often severely autolyzed before expulsion. Autolysis can obscure histological lesions and make recovery of the causative organisms impossible.

Where possible, all samples from the outbreak should be submitted to the same laboratory. The clinician might also request that only one pathologist examine all submissions relating to a single investigation. This should improve communication and consistency and make it easier to see trends in the data. If multiple laboratory submissions are made, the clinician should summarize the data in a quantitative manner. What proportion of the animals examined had the lesion of interest? What proportion of the herd does this represent?

A consistent protocol for sample collection, attention to labeling, and log of all samples collected helps ensure nothing is lost or forgotten. The amount, appropriate sample container, storage, preservation, and shipping instructions for nonroutine samples should be verified with the laboratory before the herd visit. For example, should the sample be placed in a glass or plastic container? Should the sample be shipped frozen, on ice, or at room temperature? Special care should be taken with samples for microbiology to optimize the survival of the suspected pathogen and minimize overgrowth of contaminants. Samples for toxicological analysis can be contaminated easily during collection or degrade very rapidly if the wrong container or preservative is used. Small errors can result in misleading and inaccurate laboratory results.

Banking tissue samples for future analysis is appropriate if the factor to be analyzed is stable for a known period and if the cost of collection and storage is not prohibitive. It is much better to collect tissue that will not be examined than to miss important samples. Questions raised later in the outbreak investigation could require histology on tissues not originally examined, toxicological analysis of a liver sample, or immunohistochemistry to confirm the presence of an infectious agent. Small pieces of formalinized tissue for histology, for example, do not add much to the cost of the investigation and require little if any additional storage space. Frozen tissue samples can be analyzed later for some types of toxins or trace mineral content.

Extra care should be taken in necropsies that are part of herd outbreak investigations in which large economic losses have occurred. One option is to have the herd owner transport some or all of the cadavers to a regional diagnostic laboratory where the examinations can be conducted by a pathologist under the more controlled conditions of the laboratory. Where this is not practical or possible, the examinations must be completed in the field using the best possible practices. The challenge to necropsy technique and documentation is most likely to come from litigated cases.

A *camera* can be used to record subtle clinical and pathological abnormalities. The identity of the subject animal, the date, a size reference scale marker, and the identity of the pathologist should be included in each photograph in which litigation is a potential issue. The laboratory should be notified before the samples are shipped if the case may involve litigation. Many laboratories have special "chain of custody" protocol documentation that assists in ensuring any sample results will be admissible in court. The common errors made in necropsy examinations that must be avoided in "medico-legal" necropsy of livestock include the following (Wobeser, 1996; Jaffe, 1991):

- Incomplete examination (failure to examine the brain)
- Inadequate documentation (no written report or photographs)
- Too much delay between the examination and preparation of the report
- Failing to collect samples for supplementary analysis (microbiology, histology, or toxicology)
- Improper collection of samples (inappropriate samples, unsuitable containers, insufficient preservation, inadequate labeling)
- Accidental damage to specimens (contamination with spilled gastrointestinal content or improper or rough handling of fragile tissues)
- Confusion of artifacts (autolysis or histological damage from freezing confused with important pathological lesions)
- Failure to consult with other experts
- Bias resulting from too much emphasis placed on the case history

Occasionally, tissues from "normal" animals within the herd may be required as controls or for determinations of trace mineral, heavy metal status, or parasite load. Animals sent to slaughter either for the commercial market or for in-home use should be considered as potential sources of material for this type of comparative analysis.

Observation of herd management. Many other chapters in this textbook are devoted to the detailed discussion of herd management in specialized livestock production systems. This section outlines some general points that should be considered in most herd outbreak investigations. Many veterinarians are reluctant to be perceived as criticizing the management skills of their clients. Often the management assessment consists of the simple notation "good management" (Hancock and Wikse, 1988). If there is an outbreak in the herd by definition, however, there must be some level of deficiency in management. Few common disease problems require only the infectious agent to cause substantial herd losses. Almost all outbreaks or suboptimal productivity problems result from many factors, including management. The objective of the investigation is to identify the risk factors that can be changed to resolve the current herd problem.

Questionnaires traditionally have been used to attempt to objectively evaluate herd management. Questions having yes or no or other short answers are commonly used to simplify the form. This process often provides only a superficial evaluation of potentially important risk factors. For example, many management questionnaires ask whether cattle are vaccinated for infectious bovine rhinotracheitis. This would seem like a relatively straightforward question. However, a "yes" answer provides no information on what type of vaccine was used, when it was administered, and if label directions were adequately followed to optimize the chance of an adequate immune response.

To evaluate herd management completely, the clinician must *see* how things are done. Herd management cannot be evaluated completely during a single visit. Several visits may be required to understand the operating procedures in a herd. Planned management checks do not always provide a complete picture of herd management. Herd management, for that visit, might be what the owner thinks the clinician wants to see rather than what is done routinely. The best management assessments are often collected informally as part of an ongoing process where the investigating veterinarian works with the livestock owner on a regular herd health program. Ongoing assessments provide a reference for identifying changes in herd management. Management changes may be important risk factors; however, those changes that preceded the outbreak need to be carefully differentiated from those that occurred later.

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Evaluating the nutritional status of the herd. The nutritional status of the herd is a critical area of management and often one of the most difficult to evaluate retrospectively. Disease or suboptimum productivity can result directly from inadequate nutrition such as starvation, white-muscle disease and selenium/vitamin E deficiency, or laminitis in dairy cows from rumen acidosis. Poor herd nutritional management can also contribute indirectly to many productivity and health problems. Protein-energy malnutrition during the final weeks of gestation has been associated with the failure of passive transfer in beef calves and the resulting increased risk of calf scours.

The objective of a nutritional evaluation is to determine if the feeding management in the herd could have contributed to the problem under study. Is the nutrition program adequate for the type of animal and environment? Expensive laboratory analysis alone will not address these objectives. Chemical analysis of the feedstuffs is important; however, this single report provides very little information about what is actually ingested by average animal and how much variation there is between animals.

Feed inventory. Before collecting any feed samples, the herd owner should prepare an inventory of all forages, grains, and purchased supplements. Individual lots of homegrown feed are listed by type and composition, approximate date harvested, and quantity. All purchased feeds should be listed by date of purchase, source, type and composition, and amount. Copies of all feed tags (analysis and instructions for use) or the supplier contact numbers for all commercially prepared feeds or supplements should be collected. The clinician should record which of these feeds are being used now and which have been used in the past. Any unused feed from the period when the herd problem was first noticed should also be identified. The amount of available feed stores can be verified during sample collection. Does the amount of feed on hand realistically reflect the reports of the amount fed?

Feed quality. The *visual appearance* and *physical characteristics* of the feed observed during sample collection should be recorded. Odor, color, stage of maturity, presence of foreign material (garbage, weeds) and physical form provide information necessary for proper interpretation of the feed analysis. Was the hay weathered before storage and is there any evidence of mold? Record the lengths of the silage chop and estimate the moisture content. Milk fat, rumination, cud chewing, and salivation are all decreased by chopping silage too fine (Holland and Kezar, 1995). Note the relative stem-to-leaf ratio or grain-to-forage ratio in the stored feedstuff. Chop length and moisture content should be measured in the field when possible for silage and total mixed rations. Silage pH can also be measured in the field.

Feed quality can be affected by many factors, including the following (Swecker and Thatcher, 1988):

- Weather conditions during the growing season
- Deficiencies and potential excesses of nutrients and minerals in area soil (low copper and high molybdenum regions)
- Plant maturity and moisture content at harvest time
- Application of organic acid during harvest to retard mold formation
- Ammoniation at harvest to improve protein content
- Method of storage (square, round bales or stacks; covered shelter, tarps, or no protection; upright stave silos, upright "oxygen-limiting" silos, bunker or pit silos, and bags)
- Problems with the moisture content of stored feed often resulting in heat damage or mold development
- Damage during final processing (particle size, excessive heating)
- Incorporation of feed additives (ionophores, hormones, antibiotics, buffers, minerals, pellet binders, antioxidants, vitamins, flavoring agents).

Sampling techniques. Good sample collection technique is important for a meaningful chemical analysis. The samples submitted for analysis must be "representative" of what is being fed. There can be considerable variation in the quality of feedstuffs from different fields or from feeds harvested at different times during the growing season. Proper equipment is also necessary to get an adequate sample. A good quality core sampler is required for hay sampling and an auger or probe for grain and concentrates. Silage and haylage are often the most difficult to sample representatively at a single point in time. Silage is collected by taking several grab samples from different parts of an open pit or at different times from multiple points on a moving conveyor belt. There might be substantial differences in quality in different parts of the pit or silo. To get some information from the entire pit or silo, many herd owners will collect samples from each load during ensiling and then freeze the samples for later analysis. Additional sampling of the final or total mixed ration provides a check on the adequacy of the mixing process and the actual composition compared with the "paper ration." The collection of the samples from feed storage and handling equipment may be useful particularly for cases where feed-related toxicity, such as mycotoxins, is suspected. The collection of "old feed" samples from equipment has been described (Hancock et al, 1988).

Pasture sampling is done relatively infrequently but occasionally may be necessary for the investigation of metabolic disease or trace mineral deficiencies (Hancock et al, 1988). Composite grass and composite legume samples should be representative of the major species in the pasture. If more than one soil type is present, separate samples should be collected from each soil type. The samples are best collected by cutting the plants near the roots with scissors to minimize soil contamination. Separate soil and ground water samples may also be appropriate if environmental contamination of the pasture is being considered. Toxic plants can be photographed and then collected and dried for identification by an expert in that area.

Visual inspection of the pasture is important. Is the pasture natural or cultivated domestic grass or legume? Is the amount of forage adequate for the number of animals on the pasture? There are formal methods of monitoring pasture growth and availability and grazing capacity that are not reviewed here. The location(s) of water sources and evidence of use by livestock on pasture should also be examined and recorded. The clinician should note the location and availability of any supplemental feed sources, whether mineral and salt are offered in block or loose form, whether the supplement appears fresh and is protected from the elements, and finally whether there is any evidence of recent intake.

Submission for laboratory analysis. Collect, pool, and mix thoroughly 5 to 10 samples for grain or concentrate and 20 individual samples for hay or silage from each lot of feed before submission to the laboratory. Silage samples should be placed in airtight plastic bags, stored on ice, and shipped to the laboratory as soon as possible. Do not divide hay samples after collection and before submission to the lab. Separation of the leaves and stems can result in very different results among the subsamples. The lab should be instructed to dry and grind the *entire sample* before analysis (Swecker and Thatcher, 1988; Holland and Kezar, 1995). Some laboratories only process a subsample of what has been submitted unless otherwise specified.

The feed testing laboratory should be consulted before the samples are submitted. There are a number of chemical analysis packages to select from. Feed analysis can be very

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expensive. The selected package should answer only the questions of interest. The clinician should also understand the limitations of all the requested tests. Commercial feed laboratories vary greatly in their internal quality control procedures and the types of analytical, estimation, and calculation procedures used.

Common analyses and laboratory procedures. One of the standard procedures for feed chemistry is proximate analysis. *Proximate analysis* is a set of wet chemistry procedures including dry matter content, crude protein, ether extracts (lipids and fats), ash (mineral content), and crude fiber (cellulose and lignin) (Holland and Kezar, 1995). Nitrogen-free extract (sugars, starch and some of the hemicellulose and lignin) and total digestible energy are estimated from the proximate analysis. Some of these wet chemistry procedures are still used in routine forage analysis.

Crude protein analysis reflects the total nitrogen content of the feed and alone can be misleading because it gives no indication of what percent of the protein might be unavailable because of heating damage (Holland and Kezar, 1995). An additional analysis must be requested for unavailable protein. If the amount of bound protein from heat damage is greater than 12%, the available protein and not crude protein should be used in ration evaluation calculations.

Energy can be expressed many different ways (NRC, 1996). Digestible energy (DE) is the total energy of the feed less the energy lost in the feces. DE overestimates the value of high-fiber feedstuffs. Total digestible nutrients (TDN) are similar but adjusted for digestible protein. Metabolizable energy (ME) is total energy adjusted for fecal energy, urinary energy, and gaseous energy losses. The ME can be used as a reference unit and starting point for the preferred system based on net energy (NE) (NRC, 1996). Net energy is ME minus the heat increment from fermentation and nutrient metabolism. Net energy is commonly partitioned to the energy required for maintenance (NEM), gain (NEG) and lactation (NEL). Net energy values are preferred for formulating rations because they account for major losses in digestion and utilization of the feed (Holland and Kezar, 1995).

The Van Soest method is the preferred technique for cell wall determination (Holland and Kezar, 1995). The sample is processed first to separate the soluble portion (sugars, starch, pectins, lipids, protein, soluble carbohydrates, and nonprotein nitrogen, water-soluble vitamins, and minerals) from the insoluble portion or cell wall fraction (neutral detergent fiber [NDF]). NDF (cellulose, hemicellulose, lignin, and silica) increases with the maturity of the forage at the time of harvest. NDF is negatively correlated with *dry matter intake* and is used to estimate DMI (120/% of NDF). Acid detergent fiber (ADF) remains after processing with an acid detergent. The ADF is negatively correlated with the *digestibility* of forage and is used to estimate the energy value and digestibility of feed.

Calcium, phosphorus, and other major minerals can be analyzed using wet chemistry, atomic absorption spectroscopy, or colorimetric procedures, depending on the laboratory.

In recent years, near infrared reflectance spectroscopy (NIRS) has become common. The computer compares the reflectance spectra of previous forage samples analyzed by wet chemistry with that of a new feed sample and estimates fiber, protein, mineral, and energy. NIRS can provide rapid low-cost forage and grain analyses but variation in the consistency of sample collection, storage, drying, grinding, and mixing can all affect the quality of the result. The accuracy of the result, however, is most dependent on the number of wet chemistry samples from similar forage or grains used to develop the calibration set for the system (Holland and Kezar, 1995). The calibration set used will depend on how the feed sample was described on the submission form. Proper description of the submitted sample is necessary for an accurate result. For example, submitting a 90% grass:10% alfalfa mix as a "clover hay" will result in inaccurate results using NIRS. NIRS should not be used on concentrates, mixed forages, and total mixed rations (TMRs).

Ration evaluation. The laboratory results should be examined promptly. If any of the values are substantially different from what was expected, the laboratory, in most cases, will recheck the analysis. Most laboratories will hold the original sample for a short time after the results are completed. Both the "as received" and "dry basis" values on the feed analysis report should be examined. Some computer ration evaluation programs use "dry basis" and some use "as fed." Ration evaluation programs suitable for dairy, beef, and swine are readily available and can be used with a laptop computer on farm to assess the adequacy of the ration under the observed environmental conditions. Working through this process together with the herd owner, when possible, improves his or her understanding of nutrition and his or her understanding of the time required and the value of the work.

Measuring average daily intake. A limitation of ration evaluation is the failure to obtain an accurate estimation of average daily intake. First, what and how much feed is being offered to the livestock? In some herds, weights of feed delivered each day are recorded. If possible, verify the accuracy of the scale. In most cases, however, this information is not available, and one or more representative sections of the feed in the bunk should be weighed and extrapolated based on the dimensions of the bunk. A portable calf birth weight or milk scale can be used with 5-gallon pails to weigh the feed offered in individual bunks. This type of scale can also be used to weigh a sample of small square bales. Larger feedstuffs such as round bales or a load of silage potentially could be weighed at a local truck scale.

The second task is to determine how much feed is actually consumed. This should be measured and not estimated whenever possible. This can vary greatly depending on climatic conditions for any particular day. Because the amount of feed offered will vary depending on the previous days consumption and environmental conditions, have the farmer record how much is offered over several days and determine the average value. Intake then can be estimated by weighing any leftover feed just before the next feeding (weigh back). Given the number of animals in the pen, the average intake can be determined. Feed intake within the pen can also vary dramatically among animals. The amount of variation depends on bunk management and the variation in animal age, size, and type within the group. Accurate determination of feed intake is necessary for a meaningful ration evaluation but often requires substantial time and effort on the part of both the herd owner and clinician. These figures can be roughly verified by comparing the above estimates with feed inventories and invoices from feed companies.

Feed bunk management. Feed bunk management is also an important aspect of nutritional management. Variations in the dimensions, materials, and size of the feed bunk; the timing and frequency of feeding; method of feed delivery; the presence of salt or mineral in the bunks; practice of "top-dressing"; and finally the person doing the feeding can all influence average group intake and extremes within the group (Swecker and Thatcher, 1988). The necessary amount of feeding space varies with the size of animals, number in the group, and whether feed is available "free choice" or limit fed. The available bunk space should be measured, particularly if crowding or competition appears to be a problem. Ice or mud around the bunk or waterer can affect intake adversely. The feed in the bunks should be fresh, clean

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smelling, thoroughly mixed, and free of mold and other foreign material (Fetrow, 1993). Old spoiled feed in the bunk also decreases intake. Feeder design and feed storage conditions will affect the amount of feed wastage. The feed wastage should be estimated, since this information will be needed for most computer ration evaluation programs. The method of delivery for feed supplements is also important to note. The amount of micronutrients consumed will be less on average with free choice than for force-fed livestock in which micronutrients are mixed with concentrate, silage, or a TMR.

Water quality and availability. Water quality and availability are important determinants of livestock health and feed intake. The ratio of animals to waterers in each pen should be noted. The clinician should observe animals using the water source and record any evidence of crowding or dominance behavior, stray voltage, physical access, or footing (mud, manure buildup, or ice) that appears to be limiting access to water. The investigator should determine if all automatic waterers are working properly. Is dugout, pothole, or stream water pumped to a trough, or do the animals actually enter the water to drink? Is the water clean and free of offensive odors, or are there substantial amounts of mud and manure suspended in the water because of animal movements? Is algae growth an obvious problem?

Water sampling for livestock use should include an assessment of total dissolved solids (TDS), sulfates, nitrites and nitrates. TDS in excess of 5000 ppm can reduce water intake and result in diarrhea in all classes of livestock (Jaikaran, 1993). High sulfate levels (>1000 ppm) can interfere with copper status (Larson et al, 1995) and increase the risk of polioencephalomalacia (Radostits et al, 2000). Bottles for water sampling should come directly from the laboratory where possible. Improperly cleaned containers can contaminate the sample. This is particularly important for trace mineral or organic analysis. Proper sampling technique, special preservatives, and rapid transportation are required for samples being tested for potentially volatile components. The laboratory should be contacted in advance if tests outside the routine potability parameters may be required.

Reproductive management assessment. The most practical and widely used approach to assessing reproductive management has been to ask questions during an interview or to use a written reproductive performance questionnaire. Much of the necessary information is record-based and therefore lends itself to this approach. Many of the factors involved in successful reproductive management of the herd, however, are best evaluated through on-site observation. Records analysis may, for example, target heat detection or artificial insemination (AI) technique as a potential problem. Both heat detection and AI technique can be evaluated by examining a series of reproductive indices if the records are complete and accurate. Heat detection and AI techniques can be reported verbally, but herd owners may be reporting what they think the veterinarian wants to hear rather than what is actually happening. A herd visit to observe estrus detection, semen storage, handling, and thawing techniques might be necessary (Williamson, 1987). The most reliable first-hand observations and assessment of reproductive management are probably casual observations made by the veterinarian across a number of regular herd health visits. The skills required for successful management of parturition, dystocia, and neonatal resuscitation and routine processing are also difficult to evaluate without on-site observation.

Other management problems. Depending on the type of operation, many other areas of management might have to be assessed through on-farm visits. For example, in dairy herds without observing milking procedures first hand (both morning and evening if different milkers are involved), it may not be possible to understand the origin of some mastitis problems in a herd. On-site observation is the best way to determine how cows are being assessed for mastitis, how consistently udders are cleaned and teats are dipped, whether or not the liners are allowed to slip, how well the milking machine is maintained, and whether cows are being overmilked. Recently digital video cameras have been used successfully in milking parlors to monitor and time milking procedures. The milking staff should be notified that a camera is being used.

Management deficiencies are also well-documented contributors to perinatal mortality. For example, stocking density, sanitation, rotation of feeding sites, use of shelters, wintering cows on the calving ground, and mixing of heifers with mature cows can all contribute to perinatal losses in beef calves. A walk-through of the calving and nursery facilities is usually necessary to understand calving management in the herd and assess many of these somewhat subjective issues.

Animal handling and processing techniques may be important. A number of questions should be considered and are answered best by observing processing procedures. Are the animals handled with minimal stress? Are injections given correctly? At the end of processing, does the amount of product used correspond to the number of animals processed and the label dose? How many new needles were used compared with the total number of animals processed? Are biologicals reconstituted, administered, and stored according to label directions? Are recommended implanting or castration techniques correctly applied?

All facets of management can be difficult to evaluate objectively. Hygiene can be a particularly difficult area because of the herd owner's sensitivity to what is socially desirable. Livestock owners who are questioned about their barn cleaning or bedding practices might volunteer what they try to do rather than what actually happens. For example, someone might report putting fresh bedding out twice a week. The size of the bedding pack and the cleanliness of the area can be used to verify this information. A count of the straw bales on site can also be compared with the amount of bedding used and the period over which it will be needed to further support or raise questions about the self-assessment. Without time spent on the farm listening and watching, many management problems will not be detected.

Examination of the environment. As with the assessment of management, the clinician requires an understanding of the husbandry and needs of individual species and classes of livestock to identify potential environmental risk factors. Climate, housing, population density, and air quality are all important determinants of disease risk and herd productivity and should be assessed individually for both housed and pastured groups within livestock operations.

Climate. Some classes of livestock can adapt to severe extremes of climate. Most, however, do not tolerate rapid changes in the weather conditions without some associated risk. Historical weather data, to supplement verbal reports from the herd owner, can usually be obtained from local meteorological stations for a modest fee. In addition to actual data on weather extremes and changes, the interactions of the climate with other characteristics of the animals' environment, including topography, drainage, and ventilation, can be important factors. Actual pen size, for example, can be dramatically reduced by snow cover or poor drainage (Ribble et al, 1998). A field that should be of adequate size for a given number of animals can be overcrowded and highly contaminated during certain times of the year because of water accumulation or high snow drifts.

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Population density. A numerical assessment of population density should not be calculated from the total space in the pen but from the usable space at the point in time preceding the outbreak. The range of numbers of animals in the group through the critical period should be determined and not just the average or the number at the time of the herd visit. Herd visits should be made as soon as possible after a herd problem is identified, since problematic environmental conditions are sometimes transitory. Crowding and environmental contamination can be important determinants of exposure to infectious agents by increasing the opportunity for effective contact between agent and host resulting in disease (Spangler, 1988). Topography can also be an important risk factor to consider. In addition to the direct effects on drainage, topography can affect prevailing wind conditions, exposure to wind-chill factor, and, rarely, environmental toxins (Waldner et al, 1998). Ground level and aerial photographs and topographical and local municipal or county maps are all useful for recording environmental observations.

Housing and shelter facilities. The location and type of shelter within the outdoor pen should be recorded. Sheds, porosity fencing, other types of windbreaks, and wooded areas are all used by various types of operations. Portable calf sheds (if used properly) can help minimize the high levels of contamination that often occur in these highly frequented areas. The ground conditions are also very important to livestock health and production and should be recorded. Is the ground grass covered, a dry dirt lot, a lot bedded with straw or wood shavings, or a paved dry lot? Or is the ground covered with stagnant water, deep mud, and manure? The importance of these factors varies with the class of livestock, but poor ground conditions adversely affects productivity for all species. The type and amount of bedding are important to the ground conditions, but bedding management can also affect dust levels in the pen. Air quality is particularly important in dry lots and feedlots where dust levels can potentially affect the occurrence of respiratory disease.

The clinician should walk around the perimeter of the farm and ask about any potential problems areas. Some potential environmental risks to consider are the location of carcass disposal sites, garbage dumps, fuel and chemical storage areas, and nearby industrial or mining facilities. Also, the potential for insect and predator problems on the pasture should be considered.

Good ventilation and temperature and humidity control are critical to maintaining health and productivity in housed livestock of all species. The objective evaluation of indoor ventilation may require the assistance of an expert in this area. Many parameters typically are measured depending in part on the type of animal being housed and include minimum and maximum temperature, number of air changes per hour, humidity and condensation, location and size of air inlets and fans, and presence of drafts. Specialized monitoring equipment can be used to measure levels of many suspected problem gases including ammonia, hydrogen sulfide, and carbon monoxide. Other factors to be evaluated for indoor environments include sanitation and hygiene, type and condition of the flooring, barn cleaning and waste disposal system, stall or crate design and dimensions, bedding type and adequacy, ease of movement for both animals and attendants within the unit, and adequacy of the lighting. In dairy barns, for example, at any given time more than one half of all cows lying down should be chewing their cud. If a large number of cows are standing and chewing their cud, there may be a problem with the stanchions or freestalls.

Laboratory sampling and analyses. Sampling for laboratory examination is a valuable tool for ruling out or confirming the diagnosis, determining and defining risk and exposure factors, predicting the necessity for and appropriate level of intervention, and, eventually, assessing the success of the attempts to control the problem (Hancock et al, 1988). Laboratory testing usually is the most expensive part of the investigation. Undirected "fishing expeditions" are particularly expensive and rarely productive. Tests should be selected based on whether the results are likely to directly affect management decisions (Hancock et al, 1988). Appropriate samples might include blood, milk, feces, urine, nasal and ocular swabs, biopsies or tissue samples from slaughter animals or cadavers, other fluid samples, and feed, water, and soil samples. Necropsy, feed, and water sampling has been discussed previously.

Several factors influence how successful laboratory sampling protocol will be at achieving the objectives just outlined. The type of sample selected must be appropriate for the question being asked. The animals chosen for sampling must not bias the results, and the number must be sufficient to answer the question with a reasonable degree of certainty. The samples must be collected using the appropriate technique and collection equipment, stored properly, and delivered to the laboratory before sample quality is compromised (Hancock et al, 1988).

Finally, the laboratory test selected must have acceptable measurement error, accuracy, and precision and must be able to discriminate adequately between "normal" and affected individuals. (See Chapter 2 for a complete discussion of the limits and interpretation of laboratory results.) To meaningfully interpret the test results, the laboratory should be able to provide the sensitivity and specificity of a particular test and define how the value for the normal cut-off has been established. To accurately assess sensitivity and specificity there must be a "gold standard" for the test being evaluated. Several good additional references are available that discuss the interpretation of diagnostic test results (Martin, 1988; Sackett et al, 1991).

Introduction to sampling principles. The cost of most analysis often prohibits laboratory testing of every animal in the herd. How then should the animals be selected for laboratory sampling? Sampling theory is based on the principle idea that a representative group can be selected from a population of individuals, and that characteristics of the population can be estimated from this group. *Probability sampling* is a deliberate, unbiased process in which each sampling units in a group has a known probability of being selected. The most common form is *simple random sampling*. In this case, each member of the population has an equal chance of being selected. To select a simple random sample, the clinician must know the size of the study population before sampling begins.

How can the clinician make sure each individual has an equal opportunity of being selected? To select a simple random sample from a population of a given size (N), the *random number generator* on most computer spreadsheet packages can be used to produce a list of random numbers equal to the required sample size (n). The calculation of required sample size is considered in the next section. The spreadsheet program generates a column of (n) random numbers between 0 and 1. The spreadsheet formula is used to multiply each of these numbers by "N." For the random number 0.859 and n = 100, multiply 0.859 and 100 to get 85.9, round the product up to the next whole number (86), and pick the 86th animal on the list or the 86th animal through the handling system. The next number generated by the computer may be 0.246. This number is multiplied by 100 and rounded off to 25. The 25th animal on the inventory list or the 25th animal processed then would be selected. Repeat the process and keep moving down the list until there is a complete list of sample subjects equal to the

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number suggested by the sample size calculation. *Random number tables* can also be used to generate the necessary list of animals for sampling.

The process just explained can be modified to account for selection of subjects from divisions within the larger population *(stratified sampling)*. Stratified sampling would be appropriate to ensure the selection of some animals from each age or management group within the herd. The process described above is repeated within each age or management group. The appropriate sample size is calculated using the number of animals in that age or management group within the herd.

On the surface, formal probability sampling appears tedious and complicated. Many herd owners and veterinarians will ask, "Why not just select a *convenience sample* or the first 20 cows that walk in the chute?" Ease of accessibility or any other factors that made the sample "convenient," however, also will bias the resulting factor estimate. Intentional or purposive samples selected because they are "typical" of the average within the population are also biased because the subjects are clustered around the mean and do not adequately represent the variation within the target group.

The best compromise, if herd size is not known exactly before sampling begins, is to use *systematic sampling*. Systematic sampling involves the selection of animals at equal intervals. The first animal is selected randomly from within the first interval. If 10% of 100 animals are required, a number between 1 and 10 is randomly selected. If this number were 6, then the 6th, 16th, 26th, 36th, and up to 96th animals through the chute would be sampled.

Sample size determination. Probably the most common question and often the most difficult to address is "How many samples are necessary?" There is no single correct number of samples suitable for every situation. If sample-associated uncertainty in the results is unacceptable, then every animal in the herd must be tested. This is rarely practical because of time and cost considerations; therefore a sample of total population is tested to estimate the population value. The required number of animals is based on (1) the acceptable degree of uncertainty in the final estimate, (2) the expected prevalence of the factor of interest, or, for continuous measurements, the variation in the factor within the population, and finally (3) the size of the population examined.

The number of samples required also depends on the question being asked. The three most common questions addressed within a single population include the following:

- Estimate the prevalence of a disease or characteristic
- Detect the presence of some factor or disease
- Estimate the mean (or median) of some measurement in the population

Sampling to estimate the prevalence of disease in a population. Suppose, for example, a clinician wanted to determine what percentage of a herd of 500 head of beef cows was serologically positive for *Neospora caninum* and could not afford to test the entire herd. The sample size is estimated initially based on a theoretically infinite population and then adjusted to the required sample size for the number of animals in the group of interest (Thrusfield, 1995). The sample size estimate is determined for a given level of precision or an interval on either side of the estimate within which the true prevalence will fall for some predetermined level of confidence. By convention, many sample size estimates are calculated with a 95% confidence interval.

The formula for a 95% confidence interval is as follows (Thrusfield, 1995):

$$n = \frac{1.96^2\, P(1 - P)}{d^2}$$

in which

n = the sample size for an "infinite" population
P = the expected prevalence in the population
d = largest acceptable difference from the true prevalence

The estimated prevalence (P) sometimes can be found in the literature, or previous experience might suggest a suitable estimate. If there is no available information, use 0.5. This provides the most conservative or largest estimate of sample size for the bounds and confidence level used in the calculation.

Given the *N. caninum* example, a prevalence of 10% could be predicted in the population and a 2% error on either side of that value might be acceptable. The 1.96 value in the formula is used for 95% confidence interval calculation:

$$n = \frac{1.96^2(0.10)(1 - 0.10)}{(0.02)^2} = 864$$

The last step in the calculation is to adjust this infinite population estimate (n) for the number of animals in the population under study (N). If n is very small compared to N (roughly less than 5%), then n_{adj} will approach or equal n (Thrusfield, 1995):

$$n_{adj} = (N \times n)/(N + n)$$

The infinite population estimate from the previous *N. caninum* example was 864, which is more than the number of cows in the herd. This infinite population estimate is adjusted for herd size using the above formula:

$$n_{adj} = (250 \times 864)/(250 + 864)$$
$$n_{adj} = 194$$

A sample of 194 of the 250 cows is needed to be 95% confident that (over a large number of repeated trials) the prevalence of serologically positive animals is within ±2% of the sample estimate. The formulas just provided are based on approximate methods. More exact methods are also available (Levy and Lemeshow, 1999).

There are a number of commercial software and shareware packages available to perform these calculations. To use the programs, however, the clinician must understand the required information and the limitations of the results. One of the most popular is a program called EPITABLES within Epi Info, from the Centers for Disease Control and Prevention (CDC) in Atlanta, Georgia. Instructions for obtaining the software are presented in Chapter 2. A second program available free of charge on the Internet is Win Episcope 2.0 available at http://www.zod.wau.nl/genr/epi.html.

Often other factors determine how many samples will be analyzed. Cost, weather conditions, time available to collect the samples, facilities for collection, and the interest of the herd owner all affect how many can be collected. If a fixed number of samples is collected, it is possible to calculate a confidence interval for the herd prevalence and present the precision of the estimate. Using the previous example, suppose only 25 of the 250 cows were tested and 4 were serologically positive. The 95% confidence interval for the apparent prevalence could be calculated as follows (Hancock et al, 1988):

$$\textit{Apparent or test prevalence } (P) = 4/25 \text{ or } 0.16$$

$$\text{95\% confidence intervals (CI) for } P = P \pm 1.96 \times \{[P \times (1 - P)/n] \times [(N - n)/N]\}^{-2}$$

$$\text{95\% CI for } P = 0.16 \pm 1.96 \times \{[0.16 \times (1 - 0.16)/25] \times [(250 - 25)/250]\}^{-2}$$

$$\text{95\% CI for } P = 0.16 \pm 0.14$$

$$\textit{Apparent or test prevalence } (P) = 0.16 (\text{95\% CI, } 0.02 \text{ to } 0.30)$$

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Confidence intervals provide information about the precision of the estimate. "If the underlying statistical model is correct and there is no bias, a confidence interval derived from a valid test will, over unlimited repetitions of the study, contain the true parameter with a frequency no less than its confidence level" (Rothman and Greenland, 1998). Roughly translated, the clinician would be 95% confident, based on 4 positive samples out of 25, that the proportion of serologically positive cows in the herd was between 0.02 and 0.30.

Apparent prevalence and true prevalence. In the previous example, serological status, and not actual disease prevalence, was estimated. If the actual disease status of the herd was required, the clinician would also have to account for laboratory error. The laboratory results only reflect the *apparent prevalence* and do not account for the limitations in the ability of the laboratory test to discriminate between truly affected and nonaffected animals. (See Chapter 2 for information on the interpretation of laboratory tests.) Given the sensitivity and specificity of the test, the apparent prevalence, and the sample size, the *true prevalence* and 95% confidence intervals can be estimated. A shareware program called True Prevalence within Survey Toolbox (available at http://www.ausvet.com.au/surveillance/toolbox.htm) can calculate true prevalence from the data shown previously (Cameron, 1999).

Sampling to compare the prevalence of disease between two groups. In herd outbreak investigations, laboratory sampling is often targeted to identifying the *differences between groups*. The sample size necessary to do this depends on the confidence limit and power required for the test, or the estimated value and the variance of the proportion or prevalence of animals with the attribute in each of the two groups being compared. A good estimate of the expected prevalence in at least one of the groups should be obtained from previous data, a literature search, or expert opinion. The value for the second group, if unknown, should reflect the smallest important difference between the first and second groups being compared. The variance of a proportion in which there are only two possible outcomes (a binomial outcome such as "diseased" or "not diseased") is equal to $[np(1 - p)]$ where n is the number in the group and p is the expected prevalence in the group (Altman, 1991).

The *confidence limit* is often set at 95%, but frequently used values range from 90% to greater than 99% to minimize the chance of *type I error* (α). A type I error occurs when subsequent data analysis suggests (often because of sampling error) that a real difference between the groups exists and there is none. A *type II error* (β) occurs when a real difference exists between the groups being compared and this difference is missed or is considered nonsignificant often because of sampling error (inadequate sample size). The *power* $(1 - \beta)$ is often initially set at 80% but can be set higher (90% is also used commonly).

The shareware programs Epi Info and Win Episcope 2.1 can be used to calculate the sample size for comparing prevalence between two groups. The serological status of two groups of replacement heifers could be compared to assess the effectiveness of a control program for *N. caninum*. If the prevalence in the untreated group was 25% or higher, how many heifers should be sampled to determine if the prevention program worked? In this example, an "effective program" might result in a prevalence of 10%. The sample size calculator for Win Episcope 2.0 suggests that 98 heifers from each group should be tested to detect this difference with 95% confidence and 80% power.

Sampling to compare the prevalence of disease between two groups (case-control studies). In herd investigations the clinician often needs to compare the test results between affected (cases) and unaffected (controls) animals to determine whether some risk factor has contributed to the observed disease problem in the herd. If the number of cases is limited, there are some statistical advantages to having more controls than cases up to a ratio of about 4 controls to 1 case. To calculate the necessary sample size, the number of controls per case and an estimate of the prevalence of exposure in the control group are required. The estimate of exposure in the baseline population should be made from previously published work when available. The smallest important relative change in exposure between cases and controls will then determine the sample size. This value is estimated by the *odds ratio* (see Chapter 2). The clinician must decide if a risk factor that is two times more common in the cases than controls is important or if it is only important if it is substantially more common in the cases. A larger sample size is required to detect smaller relative differences. Confidence intervals and power must also be specified. Both Epi Info and Win Episcope 2.0 can be used to calculate the required sample size for case-control comparisons.

To determine if *N. caninum* serological status was a risk factor for an abortion outbreak in a particular herd, the clinician could collect serum samples near the time of abortion. Additional samples should also be collected from up to four control cows for every aborted cow. The power of the analysis is slightly increased by having more controls than cases. Reports in the literature suggest that the relative difference in abortion risk between serologically positive and negative cows can differ by 8 or higher during an outbreak. The literature also suggests the background percentage of cows that are serologically positive could be up to 10%. If 12 aborted cows and 48 controls are tested, an odds ratio of at least 8 could be measured with 90% confidence and a power of 80%.

Sampling to detect the presence of some factor or disease in a population. Testing might be conducted to determine whether or not disease is present in a group of animals. Because no test is perfect, the veterinarian can never be 100% sure there is no disease in the herd. To be 100% confident that no animals are positive for the disease, every animal must be tested. If some defined level of uncertainty in the result is acceptable, however, probability sampling methods can be applied, as explained earlier for the estimation of disease prevalence.

The following formula can be used either to calculate the minimum number of animals to be tested from a group of a given size to detect disease above a specified minimum frequency or, conversely, to calculate the probability of finding one infected animal given a specified sample size from a larger group of known size. The calculations depend on both the expected frequency of the disease in the population and the desired confidence level. The following formula can be used to estimate either the required sample size (n) or p_1 (the probability of finding one affected animal) (Thrusfield, 1995):

$$n = [1 - (1 - p_1)^{1/d}][N - (d/2)] + 1$$

in which

N = the size of population under examination
d = the minimum number of animals that must be detectable within the population
n = the size of sample required to detect at least one affected animal
p_1 = is the probability of finding at least one affected animal in the group

Consider a herd of 150 beef cows to be screened for bovine leukemia virus status. There have been no confirmed clinical cases in the herd. Some Holstein cows occasionally have been brought into the herd from auction marts to serve as "nurse-cows" for abandoned calves. How many cows

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would have to be tested to detect a 5% seroprevalence if the minimum acceptable probability of finding at least one affected animal is 95%?

$$n = [1 - (1 - p_1)^{1/d}][N - (d/2)] + 1$$

in which
$N = 150$
$d = 0.05 \times 150 = 7.5$
n = the size of sample required to detect at least one affected animal
$p_1 = 0.95$
$n = [1 - (1 - 0.95)^{1/7.5}][150 - (7.5/2)] + 1$
$n = 49$

The FreeCalc program, which is part of the shareware program Survey Toolbox (Cameron, 1999), can calculate sample size for the detection of disease and can also account for both the sensitivity and specificity of the diagnostic test in the calculation. The sensitivity and specificity of some tests may vary with the stage of the disease. A test that performs well for detecting animals that show clinical signs may not do an equally good job of detecting disease carriers (Spangler, 1988). For example, serological and culture techniques are much more reliable for adult animals showing clinical signs of Johne's disease than for younger animals that may have no symptoms but may be carrying the organism and potentially contaminating the environment.

Sampling to estimate the mean of some value in the population. The sample size calculations presented up to this point have examined examples in which the animals have or do not have the disease in question or are positive or negative on some diagnostic test. Different formulae and information are required to estimate the mean of some continuous measurement in the group, such as trace mineral levels or average daily gain. An estimate of the expected SD, an accepted level of error in the mean, and the size of the population from which the sample is collected are required (de Blas et al, 1999):

$$n = [N \times Z^2 \times SD^2]/[(N - 1) \times d^2 + Z^2SD^2]$$

in which
n = estimated sample size
Z = Student's t-value for an expected confidence level
SD = expected SD
N = population size
d = selected accepted error (precision)

This formula could be used to calculate how many animals should be tested to estimate the whole blood selenium status of a group of 60 beef cows. Often the most difficult number to estimate is the expected SD. Ideally, previous local data would be available; however, this seldom happens. This value can be crudely estimated from the range of normal values reported by the laboratory. Many laboratories have developed a normal range based on the results of a reference set of representative "normal" animals. The samples are analyzed and the normal reference range is set at approximately ±2 SDs of the mean of these samples. One published normal range for whole blood selenium is 0.200 to 1.200 ppm (Puls, 1994). If this includes ±2 SDs, then 0.250 ppm [(1.200 − 0.200)/4] should be a useful approximation of the SD for the calculations.

The next number required is Z or the Student's t-value for an expected confidence interval. In most cases, a 95% confidence interval is used, which is equivalent to a Z value of 2.00 (Altman, 1991). This value can be obtained from the tables at the back of most statistics books. The value d or the maximum acceptable error should be based on the expected mean and the degree of precision required for the estimate. The maximum accepted error is 0.100 ppm for this example.

$$n = [N \times Z^2 \times SD^2] \times [(N - 1) \times d^2 + Z^2SD^2]$$
$$n = [60 \times (2.00)^2 \times (0.250)^2] \times [(60 - 1) \times (0.100)^2 + (2.00)^2(0.250)^2]$$
$$n = 18$$

Win Episcope 2.0 can be used to calculate the number necessary to estimate a mean given the expected SD, the population size, and the selected accepted error (precision) for a given confidence interval (usually 95%).

Sampling to compare the means of two groups. When evaluating the importance of a risk factor in a herd investigation, the clinician may need to compare the means of two different groups. For example, is selenium status an important determinant of poor calf health? This question could be addressed by collecting samples from sick and healthy calves and then comparing the average whole blood selenium between the two groups. To determine how many animals to sample from each group, the following information is necessary:

- An estimate of the mean for one of the groups. (If comparing cases and controls, the expected normal value for the population should be used.)
- An estimate of the mean for the second group. (In this example, the cut-off level between deficient and normal could be used. If comparing calf weights between two groups, the second value could be estimated after considering the minimum important difference in weight between the two groups.)
- An estimate of the standard deviation.
- The confidence level and power for the sample.

Win Episcope 2.0 can calculate the sample size for comparing means. For the selenium example, to detect a difference between a normal group (mean = 0.300 ppm) and a deficient group (mean = 0.080 ppm) with an estimated SD of 0.250 ppm (see previous section) at 95% confidence with 80% power, samples should be collected from 23 sick and 23 healthy calves.

Sample size calculations: why not just use 10% or 10 animals per group? The previous examples demonstrate that 10% of each group or 10 animals per group is often not enough to answer a question with the level of confidence and power needed to make defensible, economically important herd management decisions. The cost of laboratory analysis, however, often practically limits the numbers of samples analyzed far below what the sample size calculations suggest is required. The calculations are not absolute or perfect. Different computer programs may use different formulas and provide different answers. Many of the inputs are based on subjective judgments and the values used vary from one clinician to the next. Calculated sample sizes are not absolute requirements but rather guidelines for planning data collection. Before spending substantial amounts of time and money on laboratory analysis, the necessary sample size should be determined. This estimate can minimize the chance of collecting either not enough samples or more samples than necessary for the level of confidence required in the final results.

Serum banks in herd investigations. In many investigations, there is only one opportunity to collect laboratory samples from the herd during the critical timeframe. Because of the laboratory costs, the clinician cannot possibly direct the laboratory to analyze the samples for every potential question that could arise during the investigation. If the expenses for sample collection are less than analysis, one potential answer is *serum (or sample) banking*. Samples are collected and stored with sufficient precautions so that they can be analyzed later with minimal loss of sample integrity and quality.

Serum, if processed correctly, can be stored almost indefinitely for future analysis. A single serum sample can be

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tested for a wide variety of constituents such as immunoglobulins, trace elements, toxins, hormones, enzymes, and genetic markers (Moorehouse and Jones, 1981). Whole blood samples sometimes can be stored for future assay of some trace elements or toxins.

Most often, serum samples are used to diagnose viral or bacterial infections. The use of paired samples to compare acute and convalescent titers is one of the most commonly referenced applications of serology. In some investigations, however, the disease episode may be long past before the samples are collected (Collins, 1991). Most of the limitations of this process accompany the serological test itself. Some antibodies are transient and are detected only if the samples are collected immediately following the infection. With other tests, cross-reacting antibodies make interpretation difficult. False-positive reactions can also be caused by nonspecific inhibitors, agglutinins, or unstable red cells. False-negative reactions can occur because of immunological tolerance to the agent, poorly timed collection, or masking of results by nonspecific inhibitors (Moorehouse and Jones, 1981). Some recently developed antigen capture ELISA tests have fewer limitations than paired sera comparisons.

Careful attention to animal identification, sample labeling, and documentation is required to create a useful serum bank. Minimal sample identification should include breed, sex, age, location, date of collection, and herd size (Moorehouse and Hugh-Jones, 1981). Where possible, blood samples should be collected from the entire herd. A subsample then can be selected for initial laboratory analysis. If whole herd sampling is not practical, the method of selecting the test group should be recorded.

Ideally, a sufficient amount of blood should be collected so that 3 to 5 ml of sera can be stored per animal. If the sample could be assayed potentially for trace element concentration (e.g., zinc), the collection equipment and storage containers must be chosen carefully so the sample is not contaminated. The freshly collected blood should be allowed to clot at room temperature and then stored horizontally for several hours at 4° C before separation of the serum by centrifugation at 2000 to 3000 rpm for 10 to 15 min (Moorehouse and Hugh-Jones, 1981). The serum is removed using clean Pasteur pipettes. Cross-contamination between samples must be avoided. Some sera can be refrigerated for immediate use. The remaining sera should be frozen in 0.5- to 2.0-ml aliquots for later testing.

Conventional standard deep freezes average about −20° C, and for many serum constituents, deep freezes provide adequate preservation for short-term storage of less than 3 to 6 months. If the freezer temperature remains constant, sample quality can be maintained for up to 2 years (Moorehouse and Hugh-Jones, 1981). For prolonged storage, samples should be frozen as soon as possible after collection below −60° C. Options for long-term storage include ultra-low temperature deep freezes available at some laboratories and storage in liquid nitrogen. Hemolysis and bacterial contamination of the samples must be avoided because of resulting enzymatic destruction of serum immunoglobulins. Thawing and refreezing also increase the destruction of serum constituents. Samples should be tested as soon as possible after thawing to minimize proteolysis (Moorehouse and Hugh-Jones, 1981).

Interpreting diagnostic panels and the results of "fishing expeditions" in herd investigations. When faced with a new or unusual problem with no immediately obvious solution, there is a temptation to run a panel of diagnostic tests or to submit samples of everything for everything and see what comes up positive (the "fishing expedition"). See Chapter 2 for a discussion of the risk of false-positive results that can occur when running batteries of tests on individual animals. The risk of a false-positive result increases further when batteries of tests are used on groups of animals. A group of five tests, with an individual test, false-positive risk of 3% repeated on five animals, has a combined risk of greater than 50% for one false-positive result when used on the group. Unless the test has a specificity of 100% (and very few do), the high risk of false-positive results from using the laboratory to "fish" for an answer makes this practice very dangerous. The laboratory tests should be chosen and the results must be interpreted using the information presented in Chapter 2 (the clinical signs and other laboratory results) and considering the effect of herd size and the number of samples collected. Additional discussion of the interpretation of diagnostic tests at the herd level is covered by Martin (1988).

Examination of the herd records. The details of what records are required and what information may be available for a particular type of operation have been reviewed in Chapter 3. Additional details on the form and interpretation of herd records are given in the individual chapters for each species and production class. The quality and completeness of records vary greatly between operations. Some herds have complete, individual animal, computerized record systems, and some may appear to have little or no record of animal health and productivity.

The most challenging, and all too frequently encountered, situation occurs when there are apparently few or no herd records. Potential sources of information may include veterinary service, supply, or drug bills; auction mart receipts; old calendars, pocket diaries, and calving books; feed and supplement bills; financial records of animals bought and sold; and bulk tank receipts showing somatic cell count and bacterial numbers (Hancock and Wikse, 1988). Record quality can be a serious problem, and an informal "audit" of the records for accuracy might be useful. For herds that do not have a current inventory list, chute side collection and recording of animal identification, color, breed, age (actual or approximate), and BCS should be considered and can be performed during routine processing.

Records analysis should be performed with a laptop on farm with the herd owner present. If the investigator has questions, the herd owner may be able to answer them and the herd owner gains an appreciation for the time required to perform the analysis. This may not always be possible depending on the extent of the problem and available herd records. For more complicated problems in larger herds, it may be necessary to copy the herd records and have them entered into a software program for detailed analysis. Manual entry of individual animal data is sometimes impractical. Some software programs provide user-friendly outputs using only downloaded data from third-party agencies or summary records entered at the herd level. For DHI herds, it is usually possible to obtain a computerized herd production history. This data then can be directly imported into the common herd analysis programs. Electronic data sharing can save considerable time over that required for manual data entry and analysis.

The records can be analyzed and compared to information from other herds to determine if and how the herd performance differs from expectations. Comparisons can be made to other area herds; state or provincial averages; breed association or dairy herd improvement services reports; published production and health monitoring studies; suggested targets for production; and the historical performance of the herd being examined. The appropriate benchmarks against which to compare production vary between farms because of economic constraints, physical restrictions, time and management limitations, and other individual differences. The targets for performance change over time for a particular herd as these constraints change.

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DATA ANALYSIS: EVALUATING RISK FACTORS FOR DISEASE AND SUBOPTIMUM PRODUCTIVITY

One of the most commonly calculated measures of disease for outbreak investigations is the attack rate. The attack rate is the proportion of the group that is affected during a given period. The attack rate can be compared between those that are and are not exposed to each individual potential risk factor. To easily visualize this comparison across many different risk factors, an *attack rate table* (Table 5-1) is used to help identify the exposures most likely to be associated with disease.

The application of the appropriate statistical test allows the clinician to determine if the difference between exposed and nonexposed animals is statistically significant (Lessard, 1988; Gregg, 1996). To apply statistical methods, the investigator must clarify the hypothesis being tested and then define the *null hypothesis* or statement that the effect or association of interest is zero. For example, the hypothesis might be that low BCS is associated with increased risk of nonpregnancy. The null hypothesis would be that there is no association between BCS and pregnancy status. The next step assesses the likelihood that the data (or more extreme data) could have been obtained if the null hypothesis were true (or there really was no association). In the example presented in Table 5-1, cows with a BCS <2.5 were significantly less likely to be pregnant than those cows with a BCS >2.5 ($P < .0001$).

The correct selection and application of the statistical test is necessary for meaningful interpretation of the *P*-value. The *P*-value is derived from the resulting test statistic. The *test statistic* is a value that can be compared with the known distribution of what is expected when the null hypothesis is true or there is no association. The *P-value* is the probability under the null hypothesis that the test statistic computed from the data would be as extreme or more extreme than the observed value, assuming there is no source of bias in the data collection or analysis. Statistical testing is discussed in Chapter 2, but the redundancy is justified to some extent by the frequent misinterpretation of the *P*-value. The *P*-value is not the probability that the observed effect arose by chance. This interpretation too often leads to the incorrect belief that if the observed effect is not due to chance, then it must be real (Altman, 1991).

Many times in herd investigations, the number of animals is relatively small, particularly when differences between groups within herds are examined. Often a relationship between a risk factor and disease is strongly suspected, but nothing comes up "statistically significant" (or $P < .05$). This does not prove that the null hypothesis is true (or that there is no association), only that there is not sufficient evidence to reject it. To fully interpret the importance of risk factor data from herd investigations, additional information is needed. Some measure of the magnitude of effect or the strength of the association between the exposure (or grouping factor of interest) and disease must be calculated. The magnitude of the association and the confidence intervals suggests whether there is a tendency towards an effect that might not be significant simply because of the small sample size and resulting low power of the statistical test.

The importance of different risk factors can be compared objectively by measuring the magnitude of the association between each exposure and the outcome of interest or disease. The two common indices used to measure the magnitude of effect are the relative risk and odds ratio (see Chapter 2). To review, the *relative risk* is the ratio of the risk (or cumulative incidence or attack rate) of disease in the animals exposed to the factor of interest to the risk (or cumulative incidence or attack rate) of disease in those that were not exposed. Relative risk can be used when there is complete information about the entire herd.

	Diseased	Nondiseased	
Exposed	a	b	a + b (all exposed)
Nonexposed	c	d	c + d (all nonexposed)
	a + c (all diseased)	b + d (all nondiseased)	

Relative risk = $[a/(a + b)]/[c/(c + d)]$

TABLE 5-1

Sample Attack Rate Table for an Investigation of Infertility Problem in a Beef Herd

	Exposed Animals				Unexposed Animals			
Suspected Risk Factors	No. Affected (Not Pregnant)	No. Not Affected (Pregnant)	Total No.	Attack Rate (%)	No. Affected (Not Pregnant)	No. Not Affected (Pregnant)	Total No.	Attack Rate (%)
Bull 1	6	30	36	16.7	6	18	24	25.0
Bull 2	6	18	24	25.0	6	30	36	16.7
Body condition score <2.5	11	4	15	73.3	1	44	45	2.2
New feed supplement	8	32	40	20.0	4	16	20	20.0
Purchased replacements	3	17	20	15.0	9	31	40	22.5

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If the relative risk is less than 1, then the exposure is associated with a decreased risk of disease. If the relative risk is equal to 1, then there is no association between exposure and disease. If the relative risk is greater than 1, then the exposure is associated with an increased risk of disease. The farther the relative risk is from 1, the stronger the mathematical association is between the exposure and disease. If the 95% confidence interval includes 1, then the association is not statistically significant. The relative risk provides more information than the *P*-value alone for interpreting the data in Table 5.1. Cows with a BCS <2.5 were more likely (RR, 33; 95% CI, 5 to 234) to be nonpregnant than those cows with a BCS ≥2.5. The relative risk estimates the strength of the association, and the confidence interval relates the precision of the estimate.

The *odds ratio* can be used to measure the association between exposure and disease for any study type, but it is the method of choice for expressing the magnitude of effect in case-control comparisons. Case-control comparisons are very useful for interpreting laboratory data in herd investigations. The odds ratio (sometimes called the cross-product ratio) is the odds of being exposed to some potential risk factor of interest among the cases divided by the odds of being exposed among the controls. The odds ratio can also be defined as the ratio of the cases to controls among the exposed subjects divided by the ratio of cases to controls among the unexposed subjects. If, in herd investigations, the outcome of interest is relatively rare (<10%), then the odds ratio offers a good approximation of the relative risk of disease in the exposed compared with the nonexposed animals.

	Diseased	Nondiseased	
Exposed	a	b	a + b (all exposed)
Nonexposed	c	d	c + d (all nonexposed)
	a + c (all diseased)	b + d (all nondiseased)	

$$\text{Odds ratio} = [(a/c)/(b/d)] \text{ or } [(a/b)/(c/d)] = ad/bc$$

The interpretation of the odds ratio is similar to that of relative risk. If the odds ratio is less than 1, then the exposure is associated with a decreased risk of disease. If the odds ratio is equal to 1, then there is no association between exposure and disease. If the odds ratio is greater than 1, then the exposure is associated with an increased risk of disease. If the 95% confidence interval includes 1, then the association is not statistically significant. The odds ratio tends to overestimate the strength of relationship between exposure and disease in herd investigations, particularly if the outcome is common (>10%). The data in Table 5-1 can also be interpreted using an odds ratio. Poor BCS was associated with an increased risk of nonpregnancy, since nonpregnant cows were more likely (OR, 121; 95% CI, 12 to 1193) to have a BCS <2.5.

The calculation of confidence intervals for either the relative risk or the odds ratio is useful for interpreting small data sets. Formula for confidence intervals for both the relative risk or odds ratio can be found in many different sources. Most of the calculations can be done with a handheld calculator, but Epi Info and Win Episcope 2.0 can also be used. With very small data sets, exact calculations can be obtained from most software programs that are more accurate than the formulas suitable for manual calculation.

Because of the increasing availability of computers, difficulties with formulae and calculations are no longer the major factors limiting the application of appropriate statistical analysis; however, the clinician must interpret the results correctly. "Statistically" significant does not equal "clinically" or "biologically" significant. A very small association can be statistically significant if the sample size is high enough. Strong associations are sometimes missed if the number of animals is too small. Finally, a strong and significant statistical association between a factor and disease does not prove causation without additional information.

To assess causation, the practitioner must evaluate a number of other factors, including the time sequence of events. The time of exposure for any suspected risk factor should also be plotted on the epidemic curve. Any factor suspected to cause disease must precede the onset of the disease in time. This time relationship between suspected risk factor and outcome can be difficult to verify, however, particularly when disease outbreaks are investigated retrospectively.

Analysis of Multiple Risk Factors

The preceding section outlines the basic analytical tools required for herd investigation. These tools alone, however, often limit the investigator to analyzing one risk factor. These simple techniques do not allow the investigator to account for the interactions of multiple risk factors in disease and productivity failure. In field investigations, all of the known risk factors for the outcome of interest must be considered in formulating recommendations for control. If only one risk factor is examined, and another important factor that is unmeasured or unaccounted for is differentially distributed between the two groups, the results of the analysis could be biased and misleading. Other potential risk factors can be accounted for by limiting characteristics of the animals compared, by matching some characteristics of the animals compared, or by using stratification or various types of multiple regression analysis. These more advanced analytical methods are beyond the scope of this chapter. The clinician should consult a veterinary epidemiologist for assistance with analysis of complex data sets involving multiple risk factors. Faulty investigation design or analysis can result in inappropriate advice and potentially substantial losses in herd productivity.

SUMMARY OF INVESTIGATIONS, RECOMMENDATIONS, AND CONTROL STRATEGIES

The objective of the investigation is to identify the risk factors for disease or suboptimal productivity in the herd and then to control the problem by targeting the factors under management influence. The clinician needs to explain why the outbreak occurred. At the completion of data analysis, the most likely risk factors can be identified and used to formulate a working hypothesis or diagnosis of "best fit" (Ribble et al, 1998). The working diagnosis should consider risk factors, sources of exposure, modes of transmission, and the exposure period where applicable (Lessard, 1988). In some cases, this information is sufficient to proceed with detailed recommendations for control. In other cases, further work is required.

Sometimes the required further work is simply additional laboratory analysis indicated by the initial results. In other investigations, planned observational studies are necessary to address specific questions raised during the investigation. Earlier in this chapter, the potential for supportive epidemiological studies to investigate the importance of potential risk factors was introduced. In the following sections, the basic observational study designs (cross-sectional,

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case-control, and cohort) and the advantages and limitations of each approach are introduced.

Follow-up Observational Studies

Cross-Sectional Studies

In a cross-sectional study, data on the risk factors of interest (exposures) and disease outcomes of interest are collected simultaneously. The cross-sectional study is a snapshot of the exposure disease relationship at some particular point in time. Because all of the information is collected together over a relatively short period, this is often the least complicated and least expensive of the observational study designs. The major limitation of the cross-sectional study design, however, is that there is often no way to determine whether the risk factor preceded the disease in the animals being studied. For example, a poor BCS should be evaluated as a potential risk factor in a herd that had recently experienced high stillbirth losses. If the information on body condition is limited to observation of the cows after calving season is completed, the clinician will have difficulty verifying the time sequence of events. Did the low BCS contribute to the losses, result from dystocia-related postpartum metritis, or occur because of unrelated, poor postpartum nutrition? Cross-sectional studies are useful for examining factors that do not vary over time, such as the association between the degree of eyelid pigmentation and the risk of pinkeye in cattle.

Case-Control Studies

When the case-control approach is used, the risk of exposure to one or more risk factors of interest is compared between cases of the disease (or productivity deficit) in question and controls selected from the population at risk. Case-control studies are well suited for retrospective analysis of clinic or hospital-based records and are very efficient for examining rare outcomes. Accurate case definition and careful thought on the selection of appropriate controls is necessary to minimize bias in the results. Since exposure status is usually determined after disease status, there may be some difficulty in establishing whether exposure preceded disease. Case-control designs are often used in herd investigations in which it is possible to sample most or all of the cases, but it is not practical or possible to sample all of the nonaffected animals. Case-control methods could be applied to assess the association between failure of passive transfer and a neonatal scours outbreak by examining the concentration and amounts of serum immunoglobulins between calves with scours and healthy calves matched on calf age.

Cohort Studies

For cohort studies, two or more groups within a herd or larger population are defined according to their exposure status for some risk factor of interest and followed to determine the occurrence of disease (or productivity deficit) in each group. Because exposure status is known at the start of the study, the timing and directionality of events should be clear. When done prospectively, cohort studies can provide good quality data; however, this study design can be time consuming and expensive.

Cohort studies require extensive efforts to minimize loss to follow-up and the bias that can result if all study subjects are not included in the final analysis. Cohort studies can also be difficult when disease is recorded at a very low frequency. If the outcome of interest is rare, a very large study population might be required to achieve adequate statistical power unless the study is conducted within a high-risk population. If historical records are very good, cohort studies sometimes can be performed retrospectively. For example, available herd records could be used to compare the pregnancy rates between two different AI technicians. The herd records could be used to identify all cows inseminated by each of the technicians. The records then could be used to follow the individual cows forward from the time of insemination to determine the proportion of each group that became pregnant. Finally, the relative risk could be calculated to compare the proportion of pregnant cows for each of the two technicians.

Follow-up Investigations

No investigation is complete without a *written report* prepared for the herd owner as described earlier in this chapter. This written report may have to be supplemented with the results of later laboratory tests or longer-term field studies to identify risk factors. The case definition may need to be revised and the results from the investigation herd compared with other herds in the surrounding area (Lessard, 1988).

Clinicians should consider their responsibilities to the larger livestock industry (legal and ethical) as well as the immediate concern with improving health and productivity in this one herd (Ribble et al, 1998). If the disease is *contagious*, the investigator must consider what risk the herd poses to other livestock producers in the area and consult with the herd owner on minimizing the potential for transmission beyond the herd. If the exposure could potentially cause *food residues*, the investigator should contact the appropriate authorities for direction and advise the herd owner of his or her legal and ethical responsibilities. If the disease is potentially *reportable*, the appropriate regulatory officials should be consulted as soon as possible. If the losses are extremely severe, the herd owner should be advised to consider his or her short- and long-term goals and to get advice from a financial counselor before deciding between potential alternatives for control.

For economically significant herd problems, the investigation should not end with the identification of important risk factors and the recommendations for control, particularly where control or treatment are not well understood. Where the effectiveness of proposed control measures cannot be predicted with certainty, one infrequently used but potentially invaluable strategy for evaluating the effectiveness of control measures in the herd is the randomized controlled trial. Controlled field trials have been used, for example, to examine the impact of copper supplementation on weight gain in calves from a herd showing clinical signs of deficiency (Naylor et al, 1989).

Randomized Controlled Trials

The randomized controlled trial (RCT), sometimes referred to as a clinical trial, is a valuable tool for assessing the effectiveness of herd treatment and control procedures. Volumes have been written on the design and analysis of randomized controlled trials, and these details are beyond the scope of this chapter. This section is intended to introduce this tool, provide some references for further study, and suggest that consultation with a veterinary epidemiologist before planning or implementing the trial could save both time and expense.

The RCT is a field trial in which the subjects are distributed using a formal randomization scheme into a treatment and control group(s). Randomization is used to minimize the potential influence of other risk factors on the

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study results. The performances of the treated and untreated control group are compared to estimate the effect of the treatment procedure. Sometimes the control group is treated with the current best practice rather than no treatment at all for ethical reasons and to minimize the potential for economic loss and animal suffering as a result of the trial. For the results to be valid, the assessment should be made blind to the treatment status of the animal, the control group should be current and not historical, no other biases should be apparent, and the role of chance should be assessed using appropriate statistical analysis (Ribble, 1990). A complete understanding of the randomization process, appropriate unit of analysis, and analysis of data, including withdrawals and incomplete data, are necessary to minimize potential misinterpretations.

CONCLUSIONS

This chapter outlines the principles of herd outbreak investigations. All outbreaks and all livestock operations are different. There is not one particular format of investigation that will cover all possible situations in the field. The process is not followed in any particular order, and individual steps are often repeated many times before the information necessary to implement a successful control process becomes apparent. However, a basic outline for approaching disease outbreaks and investigations of suboptimum productivity is provided. The mathematical techniques presented here supplement the information presented in Chapter 2. With the availability of computers and software, the mathematical analysis required to investigate disease in populations is no longer tedious, time consuming, and inaccessible to field practitioners. The techniques introduced in this chapter are relatively basic, however, and situations requiring more complex analysis will be encountered that require consultation with an epidemiologist.

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CHAPTER 6

Health and Production Management in Dairy Herds

PAMELA L. RUEGG

OVERVIEW OF THE DAIRY CATTLE INDUSTRY

The dairy industry is a large and dynamic segment of the agricultural economy of many nations. In 1999, cash receipts from marketing's of milk exceeded $23 billion in the United States. In Canada the dairy industry ranks third in the agricultural sector behind grains and red meats. In recent years there have been remarkable changes in the structure of the dairy industry of developed countries. These changes include continued restructuring of the industry through reduced herd numbers, increased herd sizes and adoption of specialized management practices that encourage higher productivity. Societal trends such as increased urbanization, changes in food preferences, and unease with biotechnology will contribute to continued evolution of this industry.

While dairy herd numbers have decreased, consumption of dairy products continues to increase. In the 3-year period between 1995 and 1998, U.S. commercial disappearance of milk increased by 4.3% (Fig. 6-1). The majority of milk is consumed in the form of manufactured products such as cheese. There is strong consumer demand for convenience foods that include cheese as an ingredient. While consumption has increased, milk prices paid to the producer have stagnated. One result of stagnate milk prices has been increased farm productivity and larger herd sizes (Weersink and Tauer, 1991). In the United States the dairy industry is restructuring at a rapid pace. Dairy cow numbers have been declining since peaking at 24.1 million cows in 1940. Since 1991, dairy herd numbers have decreased by about 5% per year and in 1998, there were approximately 9.1 million cows located on 117,000 dairy farms. To meet the continued demand for milk, productivity has increased on the remaining farms. Between 1999 and 2000, per cow milk production increased by 196 kg to reach 8257 kg per cow. In the United States another response to stagnate milk prices has been an increase in the number of cows per herd. As a consequence, an ever-increasing percentage of milk is being produced on larger dairy farms. According to the U.S. Department of Agriculture, in 2000, 50% of dairy herds milked less than 50 cows, 42% milked 50 to 199 cows, and only 8% milked more than 200 cows. The volume of milk production looked markedly different with only 10% of milk produced by herds of less than 50 cows, 37% of milk produced by herds of 50 to 199 cows, and 53% of milk produced by herds of more than 200 cows. In a number of other countries, including Canada, the dairy industry functions under a supply management policy. Consequently, herd numbers and herd size demographics are more stable. In 1996, there were 30,926 dairy farms in Canada with an average herd size of 54 cows per farm. Only 1.5% of Canadian farms milked more than 123 cows.

Holsteins are the predominant breed of dairy cow, comprising 93% and 85% of U.S. and Canadian dairy herds, respectively. Jerseys are the next most popular breed (4.1% of U.S. herds) followed by Guensey (1.7%). The remaining 1.2% of herds are distributed among Ayrshire, Brown Swiss, Milking Shorthorn, and other breeds.

Another trend is the increased centralization of dairy farming in specific geographic locations. In Canada, 81% of dairy farms are located in Ontario and Quebec, 14% in the Western provinces, and 5% in the Atlantic Provinces. In the United States in 2000 the top five dairy states accounted for 53% of total milk produced. Continual increases in productivity and herd size have resulted in California becoming the leading milk-producing state. California and Wisconsin alone—19.29% and 13.99%, respectively—produce approximately 33% of U.S. total milk production, followed by the next three states: New York (7.1%), Pennsylvania (6.6%), and Minnesota (5.7%). Between 1991 and 1996 most states reduced milk cow numbers. The Western states were a notable exception to this trend. During this time period, cow numbers increased in Arizona, Idaho, and New Mexico by 23%, 38%, and 88%, respectively.

As dairy farms increase in size, the ability to attract, train, and manage labor becomes increasingly important. On small dairy farms, much of a dairy producer's time is spent performing actual physical tasks, such as milking, growing crops, and handling animals. As farms increase in size, the farmer's attention must be directed toward managing people and processes. Many successful stock handlers have personality characteristics that are not easily transferable to the people management process (Seabrook, 1984). It becomes necessary to delegate many tasks to others. Continued advances in the sciences of genetics, nutrition, reproduction, milk quality, and health management encourage farmers to learn to depend on others more for advice. These trends are also influencing veterinary practitioners that serve dairy farms. The specialization occurring on dairy farms is encouraging many dairy practitioners to develop specialized services and skills to meet the industry needs.

While the number of large dairy herds is increasing, dairy farming remains a family-based business. The 1995 U.S. Census of Agriculture reported that 86% of U.S. farms are sole family proprietorships and less than 1% are non-family-owned corporations. As herds expand, they often become structured as family partnerships or family corporations (Stahl et al, 1999). Small single-family dairy farms of less than 80 cows often require creative production or marketing techniques to generate adequate farm income. Low-input dairy operations based on grazing or production of certified organic milk are ways that some smaller farms are attempting to market and produce milk at low cost or to obtain a higher milk price. Organic dairy farming is a small but grow-

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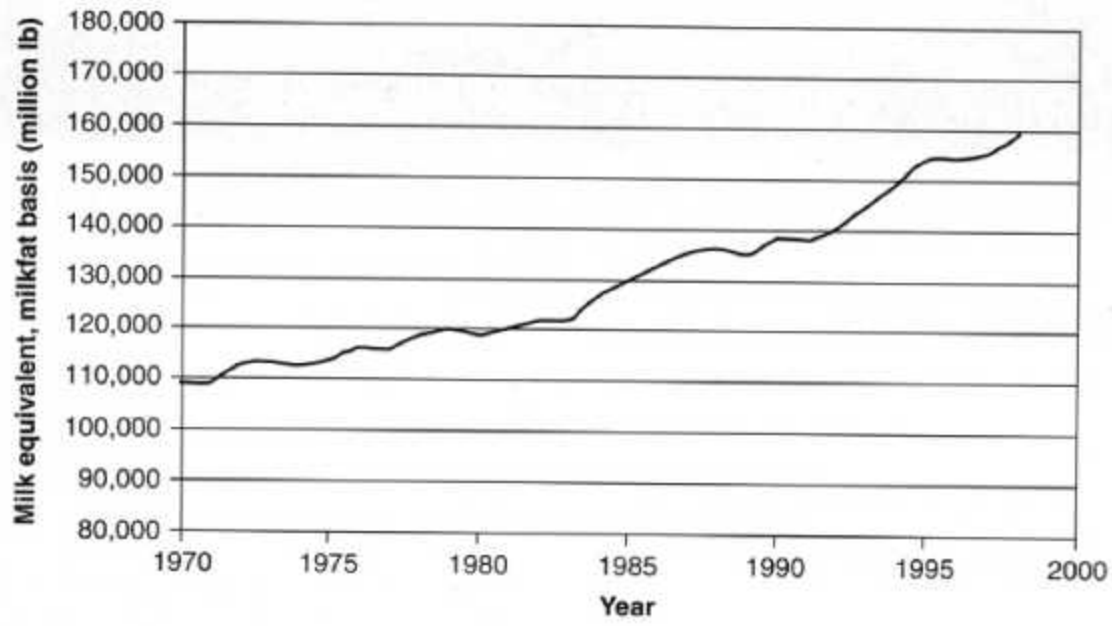

FIG. 6-1 U.S. commercial disappearance of milk.

ing segment of the dairy industry that markets milk to meet increasing consumer demand for organically produced milk. The market for organic dairy products is especially strong in the European Union (E.U.) (Vogl and Hess, 1999). The number of farmers using intensively managed grazing systems to provide forage to their cattle has also increased. Intensive grazing systems are promoted to reduce labor and purchased feed costs on smaller dairy farms.

Large dairy farms have an advantage in fixed production costs and tend to adopt production enhancing management techniques at a higher rate (Table 6-1). The adoption of bovine somatotropin (bST) is a good example of this phenomenon. In the United States, recombinant bST has been approved and marketed since 1994. In 1996 the National Animal Health Monitoring System (NAHMS) reported herd adoption rates of bST by farm size: 6.5% (operation of less than 100 cows), 18.5% (100 to 199 cows), and 31.9% (200 or more).

In past years, types of housing and milking systems were limited. Most cows were housed in confined stall-barn type facilities and allowed access to pasture according to seasonal conditions. Today most animals continue to have access to pasture, but the choice of housing system is much more diverse. In 1995 dairy operators surveyed by NAHMS reported that 24.4%, 61.4%, 47.2%, and 59.6% of lactating cows had access to free stalls, tie stalls (or stanchion), drylots, or pasture, respectively. The current design of cow housing is markedly different than in the past. Barns were traditionally designed to maximize operator comfort. In 2001 most new free stall facilities are built to maximize natural ventilation. In the past, barns were often located in a sheltered location. Barns are usually located in open fields or on hilltops to ensure adequate airflow and to optimize cow comfort. The type of milking facility is also evolving; whereas many operations report using tie stall or stanchion milking facilities, the majority of cows (55%) are now milked in milking parlors.

A wide variety of milking parlors are in use. Most parlors are highly mechanized and have been designed to minimize the amount of labor required for operation. Automatic milking machine take-off units are commonplace, and large parallel and rotary-style parlors have been designed to require minimal human input. The ultimate low-labor milking systems are the automatic milking systems ("AMSs" or "robot systems"). AMSs are designed to clean teats before milking, attach milking clusters, extract milk, detach the milking unit, spray post-milking teat disinfectant, and clean the equipment between cows. A number of AMSs are in use in Europe and Canada. In the United States AMSs are expected to be attractive to small, financially sound, well-managed, single-family dairy farms that wish to minimize labor needs.

On most farms, harvested milk is cooled before storage in refrigerated bulk tanks or milk silos. Milk is generally picked up on a regular basis (either daily or on alternate days) and transported to the processor by tanker trucks. Some of the largest farms have dispensed with bulk tanks. On these large operations (generally more than 1000 cows) milk is piped directly from the milking parlor through a precooler into a tanker truck that transports the milk to the processor when the tank is full. This type of farm often milks cows continuously throughout the day and night. Milk that is immediately transported to processors has an advantage in freshness compared with milk that is held on the farm until pickup.

The definition of "high-quality" milk is evolving. Milk quality is traditionally defined by the somatic cell count (SCC) and bacterial count in prepasteurized bulk tank milk. In all developed nations, regulatory officials set allowable maximums for SCC. Since 1986 allowable limits for SCC and bacteria have been gradually lowered. The current upper limit for bulk tank SCC is 750,000 and 500,000 cells/ml in the United States and Canada, respectively. The E.U. SCC maximum is 400,000 cells/ml using geometric means as the basis for calculation. In the United States, the Centers for Epidemiology and Animal Health surveyed 35% of U.S. milk supply from 1994 to 1997 and reported a geometric mean value of 297,000 cells/ml. Dairy herds with SCC greater than 400,000 cells/ml have been demonstrated to have a higher risk of violative antibiotic residues (Ruegg and Tabone, 2000). Many industry experts in the United States expect the regulatory limit for SCC to be lowered in future years.

Artificial insemination (AI) through the commercial distribution of frozen semen is the preferred method of reproductive management on most dairy operations. In fact, 45% of U.S. dairy operators in 1996 reported that no breeding bulls were present on their farms. An additional 35% of operations reported that they had one bull, and only 20% of farms reported more than two breeding bulls. In most of these operations the breeding bulls are used after unsuccess-

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TABLE 6-1

Selected Management Characteristics of U.S. Dairy Herds in 1996 by Herd Size

	Number Of Lactating Cows		
	<100 (%)	100 to 199 (%)	>200 (%)
Feed a total mixed ration	28.2	64.1	83.5
Forage testing	64.1	84.9	86.0
Use of bovine somatotropin	6.5	18.5	31.9
Use of prostaglandins	30.1	45.0	50.5
Contract heifer raising	2.7	6.5	18.5

Adapted from National Animal Health Monitoring System Part I: Reference of 1996 dairy management practices, U.S. Department of Agriculture, Ft Collins, Colo, 1996. Available at: http://www.aphis.usda.gov/vs/ceah/cahm (accessed February 7, 2001).

ful attempts at AI. The use of genetically elite sires has contributed to more than 150 kg/year increases in genetic merit for milk production (Funk, 1993). Declining fertility has accompanied advancements in genetic merit. It is common for dairy farms to record herd conception rates of less than 50%. Technologies such as embryo transfer, rapid hormonal assays, controlled breeding programs that use reproductive hormones, and the use of ultrasound are used increasingly on modern dairy farms. Advice by specialized veterinary practitioners is essential for farmers to sort through the complexity of reproductive choices available.

Nutritional research has advanced rapidly, especially in areas such as rumen physiology and lipid metabolism. Lactating dairy cows are generally fed either a component based ration (forages and grain are fed separately) or a total mixed ration (TMR) (forages and grain are mixed and fed together). The basis of a successful nutritional program is the determination of nutrient content of the ration ingredients through laboratory testing, formulation of nutritionally sound diets, and assurance of adequate intake of required nutrients through feed bunk management. Maintaining a stable and healthy rumen environment is difficult with component-based feeding systems, and many herds prefer TMR-based diets. TMR diets are generally based on mixing stored forages (usually haylage or corn silage) with grains (such as high-moisture corn or soybeans) and by-products such as cottonseed or locally available commodities such as citrus pulp, brewers grains, or bakery waste. On larger farms, cows are often grouped and fed diets specifically formulated to meet their production and metabolic needs. Many farms use the expertise of professional nutritionists to formulate rations.

Both farmers and their consultants routinely use computers on dairy farms. In the NAHMS Dairy '96 study, the use of on-farm computers for record keeping was reported by 15% of dairy operations but involved 37% of cows. Records were kept for an additional 13% of cows using off-farm computers. Computers are used for a variety of purposes, including monitoring milk yield. In 1996 almost 60% of dairy operations used record-keeping systems through dairy herd improvement (DHI) organizations (Losinger and Heinrichs, 1996). All DHI organizations use on-farm computers for data entry and summarization. Milk weights can be downloaded from computerized milking systems that weigh and record milk yield or can be entered at the farm by DHI technicians after manually weighing the milk. Both DHI enrollment and on-farm computer use have been associated with increased herd productivity (Losinger and Heinrichs, 1996). Computers are an integral portion of nutritional management on dairy farms, and virtually all professional ration balancing is performed using specifically designed computer software. Many large dairy farms use on-farm ration balancing software to reformulate TMR diets when ingredients are changed or moisture content is reassessed. Notebook and handheld computers are increasingly part of the veterinarian's toolkit when they visit the dairy. There are many specialized spreadsheet programs that are used by dairy veterinarians for farm problem solving. Electronic devices are available to automatically identify cows, record milk weights, record movement, monitor estrus behavior, detect changes in milk conductivity, report body temperature, and monitor feeding activity. "Fuzzy logic," herd simulation programs, and decision support software are being explored for a variety of situations including manure management, grazing programs, disease control, and replacement management.

Most producers continue to raise their own replacement animals, but an increasing number of large dairy farms contract with specialized heifer growing operations (Table 6-1). Virtually all newborn heifer calves are fed colostrum within the first 24 hours of life. Colostrum is hand-fed to most calves to ensure adequate intake of immunoglobulins. The use of mastitic- or antibiotic-containing waste milk has been related to high mortality rates (Losinger and Heinrichs, 1997). Many producers feed milk replacer to decrease the potential transmission of infectious disease. Today's Holstein heifers are heavier and taller at the withers than shown in published standards from years past (Heinrichs and Losinger, 1998). Efficient replacement programs endeavor to calve Holstein heifers that weigh 550 kg at 22.5 to 25 months of age. A variety of health management programs are used to reach this goal, including deworming and the use of oral coccidiostats, supplemental selenium, and ionophores.

Societal and Governmental Issues Related to the Dairy Industry

Changes in the dairy industry are occurring worldwide (Table 6-2). Between 1991 and 1995, North American milk production increased slightly. Mexico had the largest per-

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TABLE 6-2

Changes in Global Milk Production for Selected Regions, 1991 to 1995

Region	Number Of Milk Cows (1000 head)			Milk Production (1000 metric tons)		
	1991	1995	Change (%)	1991	1995	Change (%)
North America	17,594	17,177	(2.4)	84,984	89,639	5.5
South America	21,928	22,400	2.2	24,240	29,690	22.5
European Union	25,327	22,387	(11.6)	122,961	121,714	(1.0)
Eastern Europe	6,177	5,278	(14.6)	18,895	17,295	(8.5)
Former Soviet Union	28,935	26,418	(8.7)	74,380	56,450	(24.1)
Asia	34,728	36,534	5.2	41,106	45,982	11.9
Oceania	4,352	4,689	7.7	14,700	18,114	23.2

Adapted from National Animal Health Monitoring System Part I: Reference of 1996 dairy management practices, U.S. Department of Agriculture, Ft Collins, Colo, 1996. Available at: http://www.aphis.usda.gov/vs/ceah/cahm (accessed February 7, 2001).

centage increase in milk output in North America. The developing economies of South America and Asia also recorded large increases in production. Favorable climates and investments in the dairy infrastructure are leading to significant expansion of dairy production in Brazil and Argentina. As national economies expand and personal income rises, milk consumption tends to increase. Dairy production is well suited for developing economies, since cattle can convert forages and by-products into highly nutritious animal protein. Supply management policies contributed to a small decline in net milk production in the European Union. Dramatic decreases in production were seen in the transitional economies of Eastern Europe and the former Soviet Union. More than 95% of milk produced in New Zealand and Australia (Oceania) is used in manufactured products that are exported. Seasonal production systems based on low-cost grazing and limited supplemental feed contribute to a relatively low cost of production in these countries. The ability to export dairy products at low cost played a role in the large increase in milk production seen in this region.

Milk is a bulky and perishable commodity that tends to be consumed domestically. In 1989 to 1994, only 5% to 6% of total world milk production was traded. However, trade in dairy products continues to be a contentious issue. Virtually all developed countries maintain restrictions on imports in order to protect their local dairy industries. Most countries also subsidize exports of dairy products. The United States and Canada share about 8% of total world dairy exports. Since passage of the North American Free Trade Agreement (NAFTA), the United States has become a net exporter of dairy products to other NAFTA countries. However, trade in dairy products is an extremely small part of the dairy economy. In 1998 exports contribute to less than 3% of all U.S. milk produced. Trade in dairy products between North America and the European Union is limited because of domestic market protections.

A number of health and production issues are used as surrogate trade barriers, such as differences in sanitary standards for milk production between developed and nondeveloped countries. Differences in societal values between countries may create differing policy decisions regarding animal health and welfare. One example of policy difference is the use of recombinant (rbST) for production enhancement. In 1993 U.S. regulatory officials approved the use of bST to increase milk production of adult dairy cattle based on scientific evidence of safety of milk for human consumption. U.S. regulatory officials recognized the potential for minor side effects in cows supplemented with bST but concluded that any potential effects could be controlled by existing management techniques and would not adversely affect the overall health of the national dairy herd. In 1999 regulators in Canada and the European Union used the same data to reject applications for licensure of bST in their countries. The Canadian and E.U. regulators confirmed that milk from bST-supplemented cows was safe for human consumption but concluded that potential side effects (such as increased mastitis) were unacceptable compromises to the welfare of their national herds. Other contentious topics include management issues such as tail docking, the use of reproductive hormones, and concerns about diseases with zoonotic potential. It is likely that the veterinary community will play an increasing role in public debate regarding these ethical and public health concerns.

In developed countries, the primary goal of governmental policy is to provide consumers with safe and hygienic dairy products. Tremendous advances in productivity and efficiency of production have caused surplus dairy production in all major dairy-producing countries. On an economic basis, therefore, the objective of most governmental dairy policy is to preserve the stability of the domestic dairy industry and to maintain an adequate income level for dairy farmers. Policies used include: (1) direct price supports (the purchase of commodities at announced intervention prices), (2) direct income payments and input subsidies, (3) product use subsidies, (4) import restrictions (tariffs, quotas, and licenses), (5) supply management, and (6) trade restrictions (Blayney and Fallert, 1990).

Worldwide trends are toward relaxed trade barriers and reduced governmental expenditures to agriculture. In the United States, dairy farm support programs have been based on maintenance of a minimum milk support price through

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governmental purchases of butter, cheese, and skim milk powder; import quotas and export subsidies and classified pricing programs based on federal and state milk marketing orders. In recent years, reduced U.S. government involvement has created more volatility in milk price. As a result, some dairy farmers are attempting to manage risk through the use of futures contracts. The Canadian government also uses price supports, import tariffs, and classified pricing programs. In addition, Canada attempts to balance supply and demand through the use of milk production quotas. Supply management programs are effective in reducing surplus dairy production but can limit productivity growth of individual farms and produce entry barriers for new farmers (Beck et al, 1991). In both the United States and Canada, these programs are constantly under review and undergoing immense reform to reduce government spending.

In all countries with major dairy industries, indirect subsidies continue in the form of low-interest loans, crop insurance, water and land policy, agricultural research and extension programs, and the maintenance of government diagnostic laboratories. These programs are justified on the basis of maintaining a healthy, affordable, and abundant food supply for the nations' consumers. Veterinary practitioners are affected directly by the economic health of the industries that they serve. As governmental spending continues to decline, dairy farms need to improve the efficiency of production. Preventive medicine programs contribute to enhanced profitability for dairy farms and healthy rural economies. Dairy health and production management programs are essential for the efficient production of high-quality dairy products.

The continued need for improved efficiency has created a number of challenges for dairy farmers. Although farm processes are increasingly automated, many tasks remain dependent on physical labor. One challenge in recent years has been the availability of affordable high-quality farm workers. To meet this challenge, farm managers are increasingly turning to non–English-speaking workers. Farm labor needs in the western United States have been filled by workers from Mexico and Central America for many years. Midwestern and Eastern dairy farms are increasingly using the same source of labor. As a consequence, on many dairy farms, labor needs are met by personnel with limited English. Learning to cope with cultural differences and diverse training needs can be difficult. The need to devise standard operating procedures (SOPs), treatment protocols, and consistent quality standards is an opportunity for veterinary practitioners to expand their services to meet the emerging needs of the dairy industry.

Worldwide, population growth continues to increase the demand for food while urbanization continues to exert pressure on farmland. Many developing nations are attempting to balance agricultural development with sound environmental stewardship. A desire to protect fragile environments while meeting critical needs for food and stable agricultural economies often causes tension. In developed countries an increasingly affluent population that is often several generations removed from any farm contact may view common agricultural practices with concern. Many current agricultural issues have arisen from these points of tension. The general public increasingly views biotechnology and genetic manipulation with skepticism. While technologies such as transgenic dairy animals may be viewed by some as potential new markets for dairy products, critics may view these concepts as risky experiments. Opinions about animal welfare and animal rights are also sharply divided.

Most dairy producers recognize that profitable dairy production is based on meeting the biological and physical needs of the dairy animal. Good dairy farmers pride themselves on the care that they provide for their animals. Cow housing and handling facilities are designed primarily to meet the needs of the cow ("cow comfort") and secondarily to provide a comfortable working environment for animal handlers. Without personal farm experience, the perceptions about animal welfare are increasingly shaped by media descriptions about isolated incidents of mismanagement. Many welfare activists are distrustful of large farms and may unfairly consider them to be "factory farms" that don't adequately provide for individual animal health and behavioral needs. The American Humane Society Association has stated that: "Animal welfare is improved when livestock managers adhere to the following: (1) caring and responsible planning and management; (2) skilled, knowledgeable and conscientious stockmanship; (3) appropriate environment design; (4) considerate handling and transport; (5) access to wholesome and nutritious feed; and (6) humane slaughter" (American Humane Society Association, 2000). It is unlikely that many farmers would disagree with these broadly stated recommendations, but attempts to legislate acceptable and unacceptable production methods (such as prohibitions on dehorning or tail docking) are considered unacceptable intrusions into individual farm management systems. Veterinarians and animal production specialists will be called on increasingly to educate the public and mediate societal discussions regarding acceptable animal production practices. It is always incumbent on the livestock veterinarian to recognize the welfare aspects of food-producing animals and to promote agricultural practices that enhance the well-being of the animals. Sound health management programs are the best way that veterinarians can minimize animal disease, promote animal welfare, and provide an economically sound environment for dairy farm families and their employees.

ANIMAL AND HERD PRODUCTIVITY

Productivity of Individual Cows

In developed dairy regions the genetic potential of commercial dairy cows is very high because of widespread use of AI. The genetic potential for milk yield is unlikely realized for most dairy cows in these regions. In 1999, 85% of farm income on Wisconsin dairy farms was obtained from milk sales (Table 6-3). However, the productivity of an individual cow exceeds the value of the milk she produces. The productivity of an individual cow is the sum of the value of the milk she produces, the value of her offspring, and her individual market value when she exits the herd. Many factors influence individual cow productivity. The value of the milk may be determined in part by its composition and the type of products it is used to produce. Breed, nutrition, and stage of lactation can significantly impact the composition of milk. There is an inverse relationship between milk yield and milk composition; higher producing breeds generally produce milk with a lower percentage of components. Typical milk and fat composition for the major breeds of cattle are shown in Table 6-4. Holsteins have become the predominant breed because of their ability to produce high milk volume. Colored breeds become more attractive when productivity is defined based on specific component yields. For example, the production of approximately 2 lb of milk protein would require production of either 50 lb of 3.9% Jersey milk or 63 lb of 3.1% Holstein milk. The market value of the components varies nationally and regionally based on pricing programs and the market use of the milk (i.e., consumed as fluid milk or used to produce cheese, butter, or other products). The type of ration that is fed also significantly influences milk composition. The feeding of well-balanced

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forage-based diets generally leads to a higher percentage of milk fat than the feeding of high concentrate diets.

Individual cow productivity is also based upon longevity and the proportion of the cows' lifetime spent producing milk in contrast to time spent nonproductively. Nonproductive periods include the period from birth until first parturition and dry periods before subsequent calvings. Management decisions regarding replacement and reproductive programs can have a large impact on productivity. Heifers must be managed to reach appropriate breeding size by 13 to 15 months of age to maximize lifetime production. Milk yield is related to stage of lactation. Milk yield increases rapidly after calving, reaches a plateau about 40 to 60 days after calving, and then gradually declines at a rate of about 5% to 10% per month (Fig. 6-2). The rate of decline in milk yield is less in younger animals compared with older cows. Milk yield of primiparous cows may actually surpass milk yield of multiparous animals during late lactation. Reproductive management is vitally important to ensure that the largest proportion of a cow's total lifetime production is spent during early high-producing stages of lactation rather than late lower-producing periods. Decisions regarding reproductive efficiency often involve complex issues such as the effect of production-enhancing technologies (such as bST); the herd veterinarian is ideally suited to help the producer sort through these issues.

Milk yield increases with age. Production of first lactation animals is generally about 15% lower than second lactation animals. Productivity continues to increase with parity until about the sixth lactation; these aged animals may produce up to 25% more milk volume compared with first lactation cows. Health disorders or other management problems that reduce longevity have a negative impact on productivity.

Herds that depend on grazing generally have cyclical patterns of both milk production and milk composition. Milk yield increases when pastures are abundant (often midspring and early fall). A simultaneous decline in milk fat may occur because of lower fiber levels in the highly succulent forages. Some grazing herds attempt to increase milk component values and hybrid vigor by crossbreeding. A typical cross would be to breed high-yielding Holsteins to high-component Jerseys.

On most dairy farms the market value of offspring is limited. In 1999 the sales of calves accounted for 4% of total cash farm income of Wisconsin dairy producers (Table 6-3). Male calves are sold for either veal or dairy beef production. Female animals are most valuable as replacement animals for the dairy herd. The cost of raising replacement stock is not usually well documented and can be influenced by feed costs, mortality rates, growth rates, and reproductive management. As farms are required to become more efficient, health management programs for youngstock become vitally important. Diseases that result in reduced growth rates or excessive mortality can reduce the overall efficiency of the herd. Considerable inefficiency exists in youngstock programs. The NAHMS study estimated preweaning mortality of U.S. dairy calves to be 10.8% and the average age at first calving was reported to be 25.8 months (NAHMS, 1996). A small number of registered herds aggressively market and sell elite genetic stock. On some of these farms, profits from the sale of embryos, bulls, and other elite animals (such as cloned offspring) may exceed profits from milk volume. On these farms, preventive veterinary care and excellent reproductive programs are justified to protect the value of individual animals.

The last aspect of productivity is the market value of the cull dairy animal herself ("market cattle"). About 5% of total cash income of Wisconsin dairy farmers was accounted for by the sale of cull dairy cows (Table 6-3). Approximately 95% of culled dairy cattle are sold for slaughter purposes (NAHMS, 1996). The remaining 5% are sold to other dairy farms for production purposes. The value of cull dairy cows is relatively small compared with the value of milk and fluctuates according to beef production cycles. It is obvious that market cattle, which leave the dairy herd in better body con-

TABLE 6-3

Source of Cash Farm Income of 620 Wisconsin Dairy Farms Participating in Financial Management Programs in 1999

Source of income	Percentage
Milk sales	84.94
Calf sales	4.03
Other livestock sales	1.77
Cull cattle sales	4.74
Dividends from cooperatives	0.32
Government payments	1.16
Crop sales	0.09
Cash crop sales	1.62
Crop insurance	0.12
Machinery work	0.57
Miscellaneous income	0.64
Total cash farm income	**100.00**

Data from Gary Frank, Center for Dairy Profitability, College of Agricultural and Life Sciences, University of Wisconsin, Madison.

TABLE 6-4

Milk Composition of the Major Dairy Breeds

Breed	Milk Fat (%)	Protein (%)	Lactose (%)
Ayrshire	4.1	3.6	4.7
Brown Swiss	4.0	3.6	5.0
Guernsey	5.0	3.8	4.9
Holstein	3.5	3.1	4.9
Jersey	5.5	3.9	4.9

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dition, have higher market values than animals that leave in lighter condition. Large variation in carcass weights of culled dairy animals has been reported to occur between farms (Seegers et al, 1998). Factors that influence carcass weight include the reason for leaving the herd and the stage of lactation when the animal leaves the herd. Animals with chronic, debilitating diseases may continue to lose weight if they are retained within the dairy herd, whereas animals culled for reproductive inefficiency or subclinical mastitis may gain weight. Carcasses from culled dairy cattle are also considered to have the highest risk for antibiotic residues. Attention to culling practices and the development of SOPs for market cattle is an area that is ripe for attention from production medicine veterinarians.

Numerous diseases and management errors can affect individual productivity of dairy cows. A flow chart of factors affecting lifetime productivity is shown in Fig. 6-3. One role of the production medicine veterinarian is to maximize individual animal well being and productivity to ensure the long-term viability of the dairy operation.

Productivity of the Dairy Herd as a Unit

Net farm income is related to dairy farm productivity but is not the sole determinant of profitability (Fig. 6-4). The profitable management of a dairy herd is the result of sound business decisions and financial management combined with optimum animal care. It is only under these circumstances that the dairy herd can achieve a sustainable level of production. It is incumbent on the dairy veterinarian to encourage and promote the adoption of management techniques and preventive health care programs that enhance animal well being and allow the farm to meet its business objectives. In small farms, veterinary care is often directed at individual animals and the veterinarian is often the actual provider of technical services. As farms expand, the dairy veterinarian needs to become involved in defining systems and SOPs that allow the easy application of preventive health care programs to groups of animals. In many instances technical services (such as vaccination, hoof care, and individual animal treatments) are carried out by farm staff that have been trained to deliver treatments defined by the herd veterinarian.

Factors influencing individual animal productivity were discussed earlier. On a herd basis, ideal standards of performance and disease goals for dairy herds can be stated (Table 6-5). It is important, however, that the cost of measures used to meet performance targets not exceed the value achieved by reaching the target. One role of veterinarians serving the dairy industry is to help the producer evaluate the cost versus the relative benefit of production technologies, preventive health care programs, and management choices.

Nutritional Management

The importance of understanding applied dairy nutrition cannot be overemphasized. In most dairy herds, nutritional management is the most important determinant of herd productivity. Feed costs account for the largest proportion of variable costs for most dairies. Many common production-limiting diseases of adult dairy cattle are caused at least in part by errors in nutritional management (Table 6-6). The relationship between nutrition and productivity begins at birth. Dairy herds that reported mean age at first calving of less than 27 months and mean body weights at first calving of more than 545 kg have been shown to have higher mean milk production (Losinger and Heinrichs, 1996). The dairy feeding system must be designed to deliver necessary nutrients to each cow at the correct stage of lactation to maintain optimum productivity (Linn et al, 1996). The choice of a feeding system is associated with both herd size and production level (NAHMS, 1996). Three general types of feeding systems are used currently by dairy farmers: total mixed rations (TMRs), component feeding, and management intensive grazing (MIG). Each of these systems, when implemented correctly, can deliver adequate nutrients for a highly productive dairy herd. Each system has its own inherent challenges in the achievement of optimum productivity.

The use of TMR feeding systems has increased as more herds have adopted free-stall or dry-lot housing facilities. TMR diets have several advantages (Linn et al, 1996): cows consume the desired proportion of forages, reduced risk of digestive upset, increased feed efficiency, ability to use by-product feeds, greater accuracy in diet formulation, and reduced labor needs. The performance of herds using TMR diets can be impacted adversely by errors in ration formulation and feed delivery. Some common errors include: inadequate or nonexistent forage testing, variation in forage dry matter, variation in dry matter intakes, overmixing of diets that causes inadequate fiber levels, and overfeeding or underfeeding energy to late lactation cattle. When TMRs are fed, nutritional mistakes are often spread across the entire group

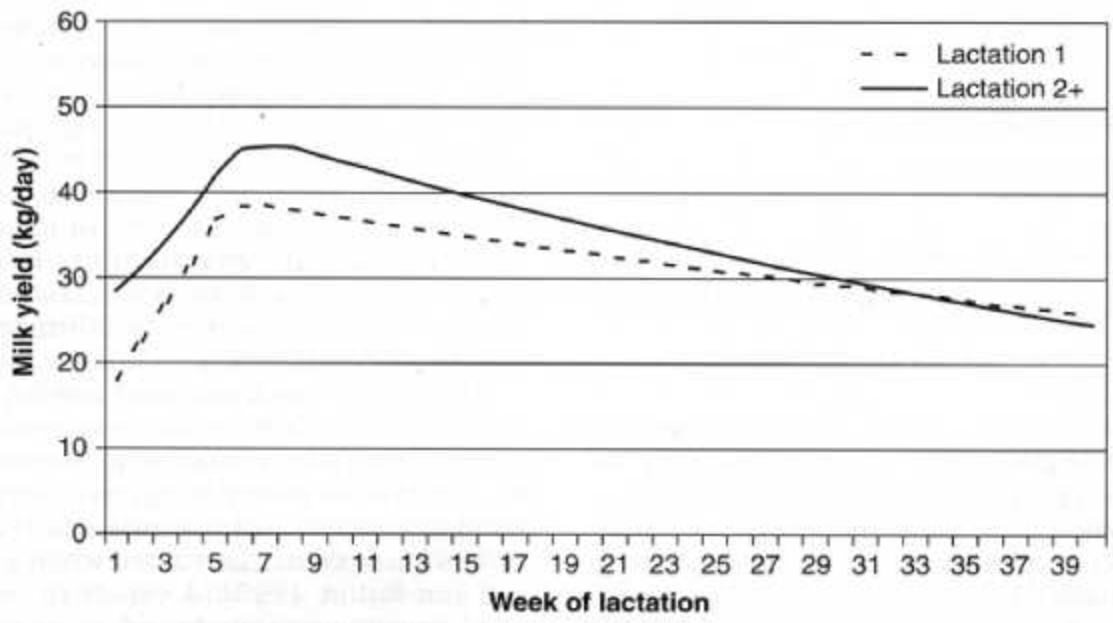

FIG. 6-2 Classical idealized lactation curves of dairy cows.

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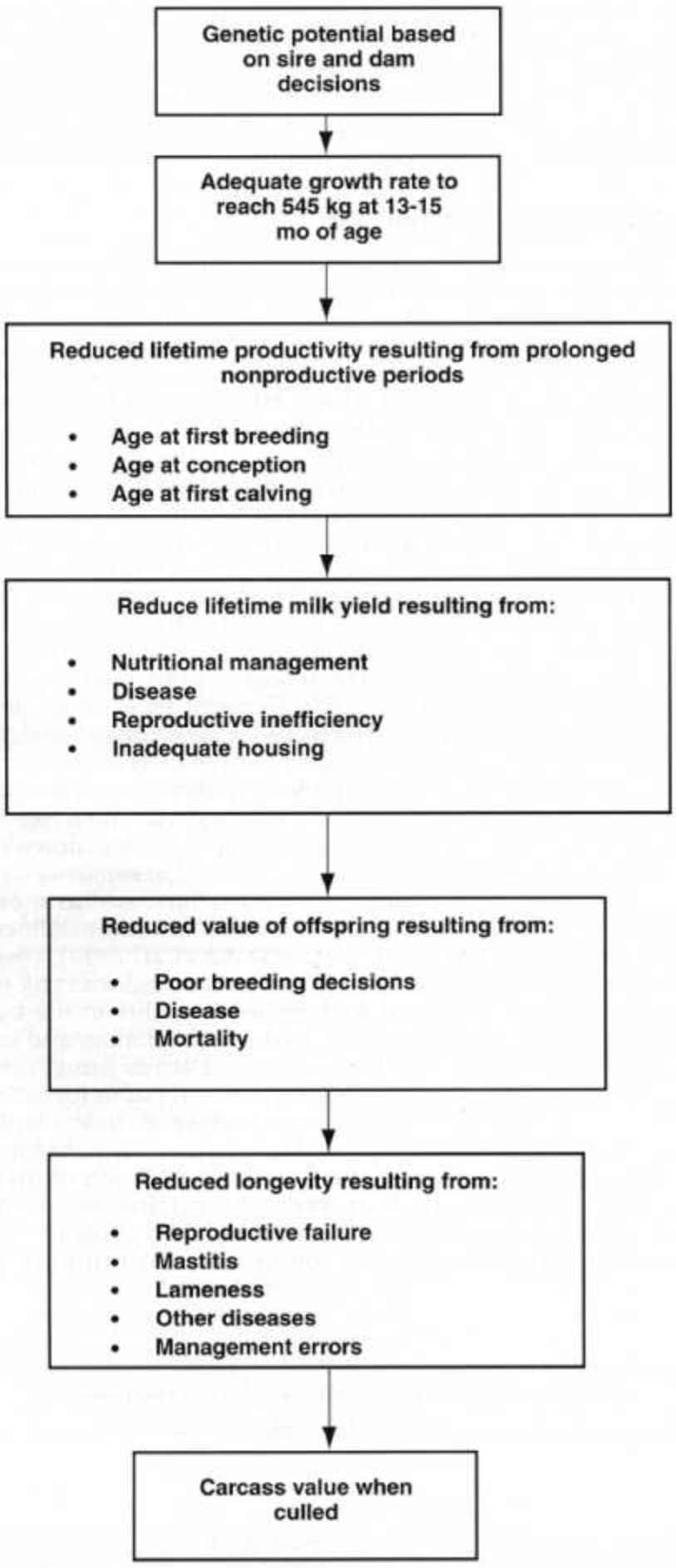

FIG. 6-3 Factors affecting lifetime productivity of an individual cow.

or herd receiving the diet. Health management programs of herds that receive TMR diets should include systems to monitor the adequacy of the ration formulation and delivery.

Component-fed herds receive grain and forage separately. Farms using these systems are often housed in tie-stall facilities. However, herds using AMS technology employ mechanized grain feeding as an incentive for cows to enter the milking robot. The successful operation of a component feeding system depends on the maintenance of a stable rumen environment while meeting the nutritional needs of modern, high-producing dairy cows. Advocates of component feeding emphasize the ability to meet the production and metabolic needs of individual cows throughout their production cycle.

Pasture-based forage systems are used in many dairy regions of the world. Management-intensive grazing systems can be used to meet the needs of modern dairy cows. In some regions of the world (such as New Zealand and Australia) pasture-based systems are the predominant method of feeding dairy cattle (Mueller, 1998). In these truly pastoral systems, nutrition is often the most limiting factor for the achievement of optimum productivity. These regions may experience significant annual variation in productivity because of year-to-year differences in growing conditions. Some herds use seasonal dairying to match pasture conditions with the energy needs of early lactation cows. Attention to reproductive management is critical for herds that attempt to breed all cows within a defined period. Production management programs for herds using MIG systems must include programs to control bloat, hypomagnesemia, and copper and selenium deficiency. Pastured cattle may walk considerable distances to harvest forages. Therefore a system to monitor and minimize lameness must be included in the health delivery system.

Reproductive Management

In most dairy herds, reproductive management is a key determinant of overall productivity. The reproductive program is the most common reason for scheduled herd visits by dairy veterinarians and is a recognized area of expertise. The dairy herd veterinarian can improve herd productivity significantly by designing and implementing sound reproductive management programs that include cost-effective strategies to meet farm goals. Farm goals for reproductive management programs must be designed individually, but all farms need to breed cows successfully to reduce involuntary culling related to reproductive failure. Reproductive disorders are the most common and costly reason for premature culling of dairy cows (Seegers et al, 1998; NAHMS, 1996). In conventional dairy herds that calve throughout the year, reproductive management can influence productivity through the following: production losses because of cows milked in later, lower-producing stages of lactation; production losses because of long dry periods; culling losses; reduced genetic potential because of the use of natural service sires; reproductive inefficiencies because of delayed age at first calving; and excessive labor and therapeutic costs associated with the reproductive program. Conception rates have decreased as herd production has increased (Fricke, 1999). High production has been related to an increased rate of double ovulations and twinning in some studies (Fricke and Wiltbank, 1999). Some herds have returned to extensive use of natural service sires to ensure that cows conceive promptly. In these herds veterinarians need to include breeding soundness exams and bull management programs in health management programs to ensure continued herd productivity.

Herds that use a seasonal calving strategy often restrict the period of calving to increase productivity and labor efficiency. Induced parturition is one strategy used to ensure that most cows calve during the desired period. An increased incidence of retained placenta and related reproductive disorders has been demonstrated when induction is used (Morton and Butler, 1995). A variety of hormonal protocols are used in some regions to aid in breeding synchronization.

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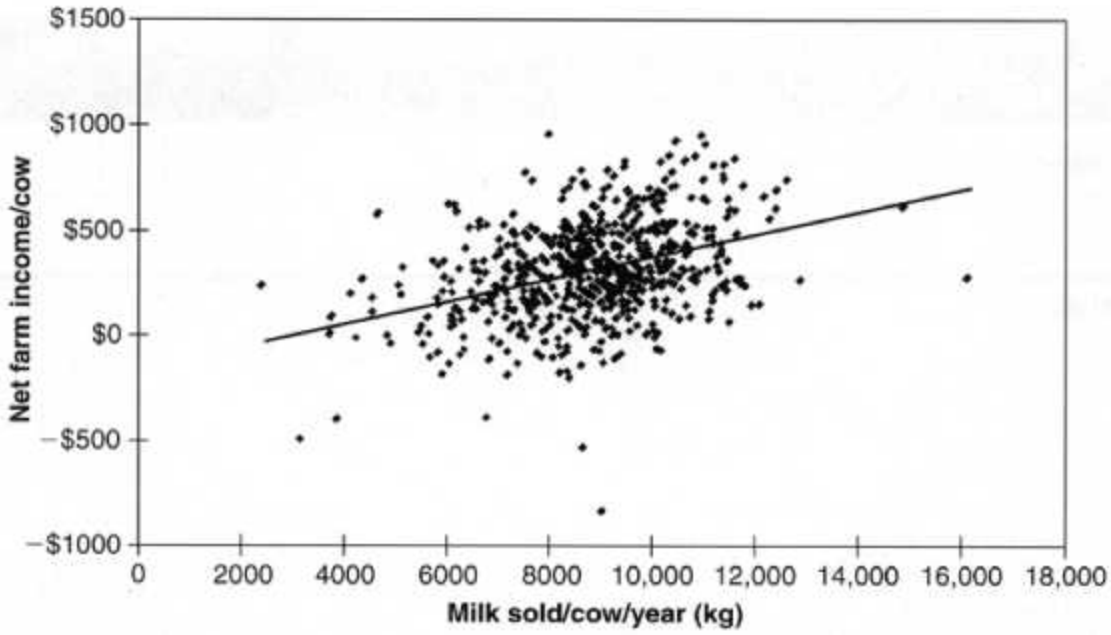

FIG. 6-4 Net farm income versus milk sold per cow for 620 Wisconsin dairy farms in 1999. (Data from Gary Frank, Center for Dairy Profitability, College of Agricultural and Life Sciences, University of Wisconsin, Madison.)

The expertise of the herd veterinarian is vital to successful use of these technologies.

Replacement Management

Calf and replacement heifer programs contribute to herd profitability in several ways and are described thoroughly in Chapter 9. Herd productivity can be impacted negatively by high mortality of replacement animals. The highest morbidity and mortality rates on dairy farms generally occur before weaning. On many farms the most significant causes of preweaning death are infectious diseases of the digestive and respiratory systems. These disorders can be controlled by well-designed health management programs that define the care and housing of the dam during the periparturient period, SOPs for the calving process, and the application of proper preventive measures (including sound nutritional programs) for the newborn calf. Healthy calves can achieve growth rates that allow them to be bred at 13 to 15 months of age and maximize the potential productivity of the overall dairy herd.

Disease Incidence

There are a number of ways that disease can reduce herd productivity. Increased culling, reduced milk or protein yield, increased adult cow mortality, and reduced reproductive efficiency are all potential outcomes of diseases of dairy cattle. Historically most veterinary attention was directed toward diseases with obvious clinical symptoms. Metabolic diseases such as milk fever and displaced abomasums (DAs), infectious diseases such as bovine viral diarrhea (BVD), and clinical mastitis were common problems for dairy farmers. Cows affected with clinical disease often exhibit a profound reduction in milk production. The duration of acute clinical syndromes is often short, but the effects of the disease may persist throughout the entire lactation. Early lactation is the highest risk period for many diseases. Disease events during early lactation may reduce peak milk yields and therefore contribute to lower total lactational yields. While management errors and lapses in biosecurity still cause epidemics of these clinical syndromes, the nature of disease has changed on many dairy farms. Through advances in animal husbandry and health management programs, many farms have minimized clinical syndromes associated with infectious and metabolic disease. The trend toward larger agricultural units and shrinking profit margins has encouraged veterinarians to shift from treatment of clinical disease in individual animals toward optimizing herd or group productivity through reduction of subclinical disease. Subclinical diseases such as mastitis, acidosis, and laminitis have emerged as major limitations to productivity on many farms. The changing nature of disease has created some diagnostic challenges. The beginning of an epidemic of clinical disease is usually readily apparent because of an unexpected increase in clinical disease to a level obviously greater than normal. The beginning of an epidemic of subclinical disease is not usually defined clearly. There is often a lag between the beginning of a problem and the recognition of its effects on the herd. In many instances veterinary practitioners must rely on indirect indicators such as SCCs, changes in body condition score (BCS), or alterations in milk component ratios to identify the beginning of an outbreak of subclinical disease. The inability to identify subclinical disease and the long duration of these syndromes allow these diseases to have considerable impact on herd productivity.

Herd Size

There is a well-demonstrated relationship between productivity and herd size. In the NAHMS Dairy '96 report, rolling average milk production for Holstein operations increased from 7487 kg for herds with less than 100 cows to 8788 kg for herds with greater than 200 cows. One reason for this relationship is the greater willingness for larger operations to adopt production-enhancing technologies (Jackson-Smith and Barham, 2000). In the United States, larger farms are more likely to adopt technologies such as TMR or bST (Table 6-1). Smaller farms tend to focus on technologies such as MIG to reduce feed costs and improve profitability.

Government policies can substantially impact herd size. Countries such as Canada that have adopted supply management systems effectively limit the annual income that a farm can achieve from the sale of milk. In this instance, achieving high individual farm milk yields may increase the efficiency of milk production (by meeting the farm quota for

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TABLE 6-5

Suggested Performance Targets for Dairy Cattle

Parameter	Target
REPRODUCTIVE PERFORMANCE	
Mean age of first calving (mo)	22-24
Mean intercalving interval (days)	365-405
Mean interval calving to conception (days)	85-125
Mean length of lactation (days)	305
Mean length of dry period (days)	45-65
Culling rate for reproductive inefficiency (%/year)	<10
Abortion rate (%/year)	<2
MILK PRODUCTION AND NUTRITION	
Deviation in daily milk production (kg drop/day/cow)	<2.5
Deviation in daily group milk production (kg drop/day)	<2.5
Ratio of primiparous milk yield to multiparous milk yield (%)	80-85
Fat tests <3.0 (% monthly)	<10
Deviation in daily dry matter intake (kg drop/cow/day)	<1
MASTITIS PREVALENCE	
Prevalence of linear scores ≥4 (%/mo)	<15
Incidence of new linear scores ≥4 (%/mo)	<5
Bulk tank somatic cell count (cells/ml, monthly)	<200,000
Individual cow somatic cell count (cells/ml, monthly)	<150,000
Number of new clinical cases/100 cows/mo	<2
DISEASE AND CULLING	
Calf mortality (% under 28 days of age)	<5
Culling rate (%/year)	<30
Prevalence of lameness (%/mo)	<5
Incidence of milk fever (% of multiparous cows calved/mo)	<10
Incidence of retained placenta (% of cows calved/mo)	<5
Incidence of left displaced abomasum (% of lactating cows)	<5
Incidence of ketosis (% of fresh cows/mo)	<15

volume, fat, or protein with less cows) but may reduce total farm income by limiting alternative farm income from the sale of replacement heifers, breeding animals, or steers. Under these circumstances the producer must carefully evaluate management decisions to ensure that higher milk yields do not cause reduced total farm income.

As herd sizes increase, some efficiencies of scale are recognized, especially regarding fixed costs such as barns and milking parlors. Herd size has a smaller impact on variable costs such as feed and veterinary expenditures. Many extremely large farms are highly specialized and contract with neighbors for feed and services such as heifer rearing. One challenge for the expanding dairy herd is to identify a reliable source of skilled labor. Labor needs are often reduced with increased specialization and automation.

The amount and productivity of pasture can influence the size of herds that use grazing. Pasture growth is influenced by soil fertility, plant type, weather, and the grazier's skill in managing animal density. In these herds productivity is determined by balancing the ability of the pasture to produce nutrients against the ability of the cows to produce milk. The size of both grazing and confinement herds are increasingly impacted by competing demands for land. In many traditional dairy regions, urban sprawl is a threat to farm growth and increasingly veterinarians are asked to participate in the planning process for farm expansions. In many communities, veterinarians also fill a local role in helping farmers educate local governments about common farm practices.

Composition of the Herd

The composition of the herd influences herd productivity. The proportion of the herd that is producing milk compared with nonproductive stock (dry cows, calves, heifers, and bulls) has an obvious impact on total herd productivity. Herd composition is the result of a number of interrelated management decisions, such as culling policy, rate of reproductive success, rate of disease, replacement management, and long-term goals regarding herd size. The ability of a herd manager to cull animals can have a significant impact on herd composition. If the pool of available replacement animals is small, many farmers are reluctant to cull aggressively. When numerous replacement heifers are available, culling may intensify, leading to a younger herd. In countries where herd production is not limited, such as in the United States, long-term plans regarding expansion often influence herd composition. A herd that is planning to grow without purchasing animals may eliminate all unforced culling and thereby end up with an older herd. Alternatively, some growing or start-up herds prefer to purchase only nonlactating cattle to reduce the risk of purchasing animals with infectious diseases such as contagious mastitis or BVD.

Text continued on p. 228

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TABLE 6-6

Common and Sporadic Diseases and Control Procedures in Dairy Herds

Disease or Production Procedure	Monitoring Techniques	Management	Primary Prophylactic Methods		Zoonotic-Potential
			Nutritional Intervention	Medication or Vaccines	
PREGNANT HEIFER OR COW					
Fat cow syndrome	Body condition score and test nonesterified fatty acids	Group and feed dry cows separately and according to needs	Yes	May need to provide supplemental propylene glycol or glycerine	No
Parturient paresis	Breed predisposition and risk increases after first episode, fresh cow SOP should include frequent observation	Feed low-potassium forages to dry cows; control the cation-anion balance and feed anionic salts if needed	Yes		No
PERIPARTURIENT COW (1 WEEK BEFORE AND AFTER CALVING)					
Parturient paresis	Fresh cow SOP should include frequent observation for staggering, or recumbency in cows every few hours for first 48 hr	Oral Ca^{+} gels to at-risk cows	Yes	Treat with calcium salt in first stage of milk fever	No
Retained fetal membranes and septic metritis	Placenta and/or malodorous discharge visible, straining in some	Adequate dietary intake of selenium and vitamin E, avoid hypocalcemia	Yes	Treat with antibiotics if septic	Yes, if brucellosis is suspected
Udder edema	Edema along belly and up escutcheon; udder swollen, very hard, milk normal	Premilk before parturition only if necessary to relieve pressure		Treat with diuretics Consider induction of parturition	No
Left-sided displacement of abomasum	Clinical evidence of inappetence, ketonuria, and decreased milk production	Feed diet balanced to provide adequate effective fiber; maintain dry matter intake	Yes		No
Simple indigestion	Clinical evidence of inappetence in rumen hypomotility	Avoid rapid dietary changes or poor quality feeds	Yes	Ensure energy intake to avoid ketosis	No

Continued

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TABLE 6-6

Common and Sporadic Diseases and Control Procedures in Dairy Herds—cont'd

Disease or Production Procedure	Monitoring Techniques	Management	Primary Prophylactic Methods		Zoonotic Potential
			Nutritional Intervention	Medication or Vaccines	
EARLY LACTATING COW (1-8 WK)					
Primary acetonemia	Screening of urine of high-risk cows for ketones	Control BCS, adapt rumen slowly to high energy diets	Yes	May supplement diet with propylene glycol or glycerin	No
Hypomagnesemia	Observation of cows daily	Avoid high-fat diets or ammoniated forages	Yes	Supplement diet with magnesium	No
Postparturient hemoglobinuria	Checking of phosphorus status	Ensure adequate dietary phosphorus	Yes	Avoid feeding of rape, cabbage, or other cruciferous plants	No
Subclinical laminitis	Observation of hoof wall or sole lesions with or without lameness	Avoid rumen acidosis and balance carbohydrate levels, provide adequate cow comfort	Yes	Administer foot baths; balance the concentration of fiber in the diet; trim feet regularly	No
Right-sided displacement of abomasum and cecal dilatation	Early detection of illness	No reliable preventive technique; assess nutritional status	Yes	Feed a balanced diet and feed roughage during dry period to ensure rumen fill	No
NEWBORN CALF (BIRTH TO WEANING)					
Acute diarrhea caused by *E. coli*, rotavirus, coronavirus, *Cryptosporidia* spp.	Daily observation for clinical disease, checking serum immunoglobulin or protein levels at 24-48 hr of age	Ensure adequate obstetric assistance at birth, if necessary, hand-feed 4 L of colostrum in first 12 hr	No	Vaccinate pregnant cow with vaccines containing K99+ *E. coli*, rotavirus, and coronavirus antigens	Yes for *Cryptosporidia*
CALF (WEANING TO 6 MO OF AGE)					
Unthriftiness and suboptimum growth rate caused by subclinical parasitism	Monthly body weight and height; fecal egg and oocyst counts; observation of diarrhea, weight loss	Feed adequate diet to support optimum growth rate; pasture rotation to avoid massive larval infection	No	Strategic use of anthelmintics, ionophores, and coccidiostats dependent on local epidemiology	No

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Enzootic calf pneumonia	Observations for paroxysmal, harsh upper respiratory tract coughing, and tachypnea	Provide clean, dry, well-ventilated, individual calf housing	No	Medicate feed with tetracycline for few weeks during period of convalescence if appropriate; develop herd-specific vaccine recommendations	No
Infectious bovine rhinotracheitis, clostridial diseases, leptospirosis, brucellosis, bovine viral diarrhea	Observation of fever, dyspnea, cough; sudden death myositis; red urine, mastitis, abortion; diarrhea and mucosal erosions	Develop a calf biosecurity plan	No	Develop herd specific vaccine recommendations	Yes for leptospirosis and brucellosis
HEIFER (6-15 MO OF AGE)					
Supernumerary teats	Inspection at 6 months of age	Remove all supernumerary teats surgically	No		No
Traumatic reticuloperitonitis		Feed hay from string-tied bales only; all concentrates should be passed over a magnet	Yes	Administer reticular magnet to all heifers nominated as herd replacements	No
Suboptimum growth rate	Measurement of height and weight monthly and comparison with standards	Ensure adequate nutritional intake or delay mating heifers until optimum mating weight achieved	Yes		No
Coccidiosis	Observation for diarrhea, dysentery, poor growth	Provide hygienic housing conditions	No	Routinely feed ionophores	No
Bovine viral diarrhea	Observation for diarrhea (sporadic cases: most die); serology for titers and detection of persistently affected animals to be culled	Develop a heifer biosecurity plan	No	Modified live vaccines; test herd additions for persistent infection before purchase	No
Clostridial disease	Observation for sudden deaths and typical lesions	Performing special techniques for some diseases, such as controlling liver fluke for black disease; clean castrations and tail docking	No	Vaccinate with eight-way vaccine if not done earlier; vaccinate before tail docking or castration	No
Intestinal helminthiasis	Regular observations of performance, especially if on pasture; fecal examination for worm eggs	Establishing pasture management to avoid heavy larval infestations	No	Strategic dosing with anthelmintics	No

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TABLE 6-6

Common and Sporadic Diseases and Control Procedures in Dairy Herds—cont'd

Disease or Production Procedure	Monitoring Techniques	Management	Primary Prophylactic Methods		Zoonotic-Potential
			Nutritional Intervention	Medication or Vaccines	
DISEASES OF DAIRY CATTLE NOT NECESSARILY RELATED TO THE PRODUCTION CYCLE					
Infectious Diseases					
Respiratory					
Pneumonic pasteurellosis	Sudden onset of fever, cough, dyspnea, toxemia	Maintain adequate ventilation; avoid stresses of handling and transportation of cattle shows; develop biosecurity program	No	Consider use of antimicrobials in an epidemic; develop specific herd vaccine recommendations	No
Viral interstitial pneumonia (bovine respiratory syncytial virus)	Sudden onset of dyspnea, cough, fever, not toxemic; wheezes over lungs, elevated body temperature	Same as for pneumonic pasteurellosis	No	Treat secondary bacterial infections; develop specific herd vaccine recommendations	No
Infectious bovine rhinotracheitis	Sudden onset of fever, cough, dyspnea	Same as for pneumonic pasteurellosis	No	Vaccinate calves at 6 months of age and cows annually	No
Lungworm	Observe for chronic coughing in calves	Manage pastures to minimize larval contamination	No	Administer strategic treatment with appropriate anthelmintics; monitor irrigated pastures	No
Atypical interstitial pneumonia	Not possible; put pilot one or two cattle on suspect pasture	Restrict dust in barn	No	Feed monensin if allowed before turn out on pasture	No
Enteric					
Winter dysentery	Explosive herd outbreak, severe diarrhea; brief, nonfatal illness	Sanitation and hygiene; effective manure disposal	No		No
Salmonellosis	Diarrhea and toxemia; fecal serotest for *Salmonella dublin* carriers	Sanitation and hygiene; check for asymptomatic carriers	No	Vaccinate as appropriate	Yes
Coccidiosis	Diarrhea, dysentery	Sanitation and hygiene; avoid crowding and fecal contamination of feed	No	Mass medication of feed and water for large herds raising many herd replacements	No

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Bovine viral diarrhea	Acute diarrhea or abortion infection is ubiquitous		No	Vaccinate breeding females at least 3 weeks before breeding	No
Johne's disease	Chronic diarrhea	Eradication by identification and culling of infected animals	No	Don't feed waste milk or pooled colostrums to calves; separate calves from dam; ensure hygienic calving environment; vaccine available in some areas to control disease	No
Intestinal helminthiasis	Diarrhea, wasting, egg counts	Pasture management, improved husbandry	No	Strategically administer of anthelmintics, if economical	No
Bovine papular stomatitis	Fatal illness with profuse mucopurulent ocular nasal discharges, ophthalmitis, oral mucosal erosions, terminal encephalitis, lymphadenopathy	Avoid contact with lambing ewes	No		No
Bovine malignant catarrh	Fatal illness with profuse mucopurulent ocular and nasal discharges, ophthalmitis, oral mucosal erosions, terminal encephalitis, lymphadenopathy	Avoid contact with lambing ewes	No	Very sporadic disease; no control program warranted	No
Foot-and-mouth disease	Herd affected; lameness, sore mouth, milk yield drop	Prevent introduction of carrier animals into countries where disease does not occur	No	Eradication by slaughter of herd and contact herds in free countries; vaccination in countries where disease endemic	No
Bluetongue	Clinically identical with chronic bovine virus	Avoid introduction of infected animals; insect control	No	Cattle are significant carriers for sheep	No
Skin and feet					
Warble fly infestation	Lumps under skin		No	Regular strategic use of insecticides	No
Pediculosis	Itching, dandruff, hair rubbed; lice visible; some blood loss; seasonal	Thin cattle most susceptible	No	Regular use of insecticides	No
Fibropapillomas	Observe for appearance of warts	Isolate infected animals	No	Autogenous or proprietary vaccines usually used as treatment	No

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TABLE 6-6

Common and Sporadic Diseases and Control Procedures in Dairy Herds—cont'd

Disease or Production Procedure	Monitoring Techniques	Management	Primary Prophylactic Methods		Zoonotic-Potential
			Nutritional Intervention	Medication or Vaccines	
DISEASES OF DAIRY CATTLE NOT NECESSARILY RELATED TO THE PRODUCTION CYCLE—CONT'D					
Pseudocowpox; mammillitis	Observe for characteristic lesions on teats	Strict hygiene in milking parlor	No	Iodophor teat disinfection preferred	No
Ringworm	Obvious skin lesions of scabs and alopecia	Sanitation, hygiene; avoid overcrowding	No	Griseofulvin if allowed	Yes
Dermatophilus infection (mycotic dermatitis)	Tenacious, widespread scabs; hair loss	Treat or remove affected animals	No	Individual medication of each affected animal with antibiotics to remove source of infection	No
Footrot	Lameness, crack in foot cleft, swelling	Provide well-drained, stone-free alleyways	No	Daily foot bath using zinc sulfate or copper sulfate	No
Digital dermatitis (Mortellaro's disease, hairy foot warts)	Lame cows; distinctive lesions, hind feet, proximal to plantar/palmar interdigital space; circular, raised, proliferative, red, pungent, painful, filiform papillae protrude from surface	Observe for lameness and examine feet for lesions	No	Topical oxytetracycline spray for individual cases; footbath for treatment and control of groups of animals	No
Sudden death diseases					
Clostridial diseases	Sudden death; may be swollen leg (blackleg, malignant edema); hemoglobinuria (bacillary hemoglobinuria)	Dispose of infected carcasses properly	No	Vaccinate all animals for clostridial diseases in endemic areas	No
Anthrax	Sudden death	Dispose of infected carcasses properly	No	Vaccinate all animals for anthrax in endemic areas	Yes
Nervous system					
Haemophilus	Number of cattle affected with somnolence, recumbency, blindness; synovitis, pneumonia, pleurisy, endometritis	Survey constantly, treat early, avoid stress	No	Vaccinate in outbreak; vaccinate calves annually before weaning; consider mass medication in face of an outbreak	No

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Listeriosis	May be number affected; observe for neurological signs, especially circling	Cease feeding ensilage; may be source of infection	Yes, poorly ensiled forages	Avoid poorly ensiled forages	Yes, if raw milk is consumed
Rabies	Posterior paralysis, slack jaw, dribbling saliva, choking; occasionally maniacal	Avoid contact with wildlife	No	Vaccinate in endemic area	Yes
Other					
Infectious keratoconjunctivitis	Lacrimation, photophobia, keratitis	Fly control	No	Treat with long-acting tetracyclines	No
Brucellosis	Monitor abortion rate; greater than 2%, check cows serologically with agglutination test for brucellosis; cull positives	Eradicate by test and slaughter	No	Vaccinate calves in initial stage of eradication program; adult vaccination permissible in some countries	Yes
Leukosis	Serological testing	Eradicate by test and slaughter; maintain closed herd	No	Avoid multiple use of needles or other equipment that comes in contact with blood	No
Leptospirosis	Abortion storms, mastitis, hemoglobinuria in calves	Avoid contact with carrier animals; hygiene and water control	No	Control rodents and deer populations; frequent vaccination in endemic areas	Yes
Tuberculosis	Regular herd or area testing	Cull reactors; quarantine until tests clear; prevent introduction of infected animals	No	Avoid contact with wildlife in areas where disease is endemic	Yes
Actinomycosis	Observe osteomyelitis of bones of jaw	Cull affected animals quickly; disinfect feed troughs	No		No
Actinobacillosis	Observe myositis of tongue	Treat or cull quickly; disinfect feed troughs	No		No
Contagious bovine pyelonephritis	Red urine, fatal subacute illness	Cease natural breeding; isolate affected animals; hygienic disposal of contaminated bedding	No	Prophylactic treatment with penicillin in high-risk situation	No
Anaplasmosis	Wasting disease, with fever peaks; monitor by complement fixation test	Insect control; prevent infection through careful disinfection of instruments	No	Vaccines widely used in endemic areas best procedure	No

BCS, Body condition score; *E. coli, Escherichia coli; SOP,* standard operating procedure.

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These herds are often composed of almost all first lactation animals.

Stage of Lactation

Ideally, herds that calve on an annual basis maintain an average 150 days in milk. This goal is derived from a calving interval of 365 days that is composed of a 305-day lactation and a 60-day dry period. In this instance 8.3% of the herd would calve and dry off each month, causing stable herd population and efficient milk production. Herds that calve seasonally or semiseasonally to coordinate peak milk yield with seasonal pasture conditions do not attempt to reach this goal. The goal in those herds is to calve in a narrow time frame, and the stage of lactation will progress as the season progresses.

Age

The age of dairy cattle influences herd productivity. It is reasonable for the manager of a herd that is composed primarily of younger animals to have lower expectations for milk volume. The distribution of age groups within a herd is related to the risk of acquiring a number of disease syndromes. Mastitis and reproductive inefficiency are more prevalent in older age groups. Some diseases (such as milk fever) are uncommon in first lactation animals. The production medicine veterinarian should take into account the proportion of animals that are at risk for disease when setting appropriate targets of herd performance. Herd age can change as the result of disease events or management decisions. When involuntary culling is increased through disease, herd age may decrease because of reduced longevity. When reproductive performance is poor, herd age may actually increase because of a reduced pool of replacement animals. Herd age should also be considered when grouping and feeding decisions are made. Social dominance in groups of cattle is based on age. In many confinement operations, grouping younger, first-lactation animals separately from older animals has been shown to increase feed intake and improve productivity.

Environmental Conditions

Even in the best housing situations, environmental conditions can affect herd productivity. Higher producing cows have larger dry matter intakes, generate more internal heat, and are less tolerant of high ambient temperatures. Weather conditions that combine high ambient temperatures and high humidity without periods of cooling generally cause depressed dry matter intakes and reductions in milk yield. The increased concentration of dairy farming in regions that experience considerable periods of high temperatures has resulted in more seasonal variation in milk output. Farmers have adopted a variety of systems to combat heat stress. Many new facilities are constructed with large open sides (often greater than 4.3 m high) and ends. These modern facilities often use fans and cooling systems to keep cows comfortable. Older enclosed facilities can be retrofitted with tunnel ventilation systems to provide adequate air movement.

Drying Off and Dry Cow Management

The dry period is recognized as an important portion of the overall management cycle of dairy cattle and is an important component of herd productivity. Most successful dairy producers recognize that the dry period is not the end of a lactation cycle but the beginning of the next lactation. Risk factors for most postpartum diseases of dairy cows occur during the dry period, with clinical signs of disease becoming evident after calving. Diseases such as hypocalcemia (milk fever), hypomagnesemia, udder edema, ketosis, DA, and mastitis all often begin during the dry period. Dairy health management programs focus many preventive practices such as vaccination, hoof care, and nutritional monitoring during this period.

The length of the dry period influences milk yield in the subsequent lactation. When milk yield ceases, nonsecreted milk is absorbed and udder secretory cells are rapidly lost. This process (termed "involution") is usually complete within about a 2-week period after milking is terminated. Immediately before calving, hormonal changes initiate rapid proliferation of milk secretory cells. The length of the dry period can influence the proliferation of secretory cells. The recommended dry period is 6 to 8 weeks. Dry periods of less than 40 days have been demonstrated to reduce milk yield in the following lactation (Dias and Allaire, 1982). In one study, a dry period of 4 weeks resulted in about 2.5 kg/day less milk compared with a 7-week dry period (Sorensen and Enevoldsen, 1991). Dry periods that are too long often lead to excessive weight gain and reduced production efficiency. Both short and long dry periods are most common when breeding dates are uncertain because of either bull breeding or inaccurate (or missing) reproductive records.

The process followed for ending a lactation should be well defined. Cows should be dried off by abrupt termination of milking followed by appropriate intramammary dry cow treatment. High-yielding cows can be dried off successfully in the same fashion, but it may be necessary to reduce milk yield rapidly by temporarily limiting access to water for 12 to 24 hours. Water intake should not be limited during periods of heat stress. Cows that are receiving bST should receive their last injection no later than 3 weeks before the expected dry date. BCS at dry off should be within the target range of 3.00 to 3.25 (on a 5-point scale). Cows that are overconditioned should not lose weight during the dry period, but a moderate amount of condition can be added safely to underconditioned cows (<3.00).

Culling Program

Decisions regarding cow removal can significantly impact productivity of the dairy herd. Culling rates can vary dramatically between herds. In 1995 U.S. farmers reported an adult cow removal rate of about 27.8% (24% sold, 3.8% died) (NAHMS, 1996). A study from England reported an annual culling rate of 23.8% (22.0% sold, 1.8% died) for 1990 to 1992 (Esslemont and Kossaibati, 1997). The rate of disease has a strong correlation with culling rates. Fertility, mastitis, and lameness are commonly reported reasons for cow removal. In some instances culling is increased because of disease control programs; in England 7.4% of culling was related to control programs for bovine spongiform encephalopathy (BSE). Culling is an important aspect of controlling other diseases such as bovine tuberculosis, brucellosis, Johne's disease, and chronic mastitis caused by some contagious mastitis pathogens. When culling is excessive because of disease, the farmer cannot select cows to cull based on productive potential and herd productivity may be affected adversely. Cow culling practices are reviewed thoroughly in Chapter 7.

Quality of Labor

The final aspect of farm productivity is the managerial ability of the dairy farmer. A dairy farm is a complex system that

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requires the ability to make numerous interrelated decisions about animals, crops, people, and financial management. Farm owners need to be able to devise monitoring systems that enable sound decision-making based on realistic data. Successful farm managers are also good at understanding how and when to seek advice. On small farms dependent on family labor, the herd owner is often responsible for all aspects of farm management and animal handling. On large farms the ability of the herd owner to employ animal handlers with excellent stockmanship can determine herd productivity. Regardless of farm structure, the relationship between animal handlers and cows can influence milk yields (Seabrook, 1984).

INTERACTION BETWEEN HEALTH AND PRODUCTION

A dairy farm is a complex interrelated system that requires a great deal of coordination to achieve optimum productivity. Each day, the dairy farm manager is required to make decisions about subjects as diverse as environmental stewardship, financial management, cow health, and personnel management. Almost every management decision has the potential to either directly or indirectly impact farm productivity and profitability. In addition, some farm conditions such as weather cannot be controlled by the farmer. For example, a farmer may elect to plant a new variety of corn to use as silage after harvest. Seasonal growing conditions may cause nutrient values or yields that are considerably different than expected. At this point the farmer may need to add grain to the diet to meet nutrient requirements of the cattle. The addition of grain may increase feed expenses (and limit available capital for other farm operations) and potentially reduce effective fiber levels. With lower fiber levels, subacute ruminal acidosis may develop in some groups of cattle, causing reduced yields, increased lameness, and increased culling. Cows may experience excessive body condition loss and reduced conception rates. Eventually, there may be inadequate numbers of replacement animals available to maintain herd size unless heifers are purchased from an outside source. Purchased animals may introduce contagious diseases unless an effective biosecurity plan is in place. Multiple and seemingly unrelated decisions on dairy farms can produce a cascade of effects that affect farm productivity and ultimately farm profitability.

The dairy health and production management program is one mechanism that allows for consistent assessment and discussion of the farm situation. There are a multitude of issues that the production medicine practitioner should recognize, and the cause of problems is not always the most obvious risk factor. For example, dry cow management and housing are often neglected during periods of farm expansion. One manifestation of inadequate dry cow management may be an increase in mastitis of recently fresh cows. The first impulse may be to review milking procedures for fresh cows or to revise early lactation protocols. In reality, many environmental mastitis infections are acquired during the dry period and manifest as clinical mastitis after calving. Appropriate intervention therefore needs to be directed at the high-risk periods immediately after dry off and immediately before calving. Ideally, the production management program would include a proactive assessment of dry cow needs before the expansion occurs.

The interconnectedness of the dairy farm system often results in decision making based on imperfect knowledge. In many instances farmers manage the separate enterprises (crops, replacement herd, milking cows, financial, and personnel) without full consideration of the impact of one decision on the entire system. Sometimes simple financial tools such as partial budgets are used to assess the economic impact of management decisions. Other times, simple computer spreadsheets are used to predict the effect of management changes to the entire herd. In some instances computer simulation models have been developed to forecast the outcomes of management changes to the entire farm system. Computer simulation is based on a thorough understanding of the underlying processes and the use of realistic assumptions that apply to the situation under study. At some point computer simulation will probably be used in the field on a regular basis to aid in farm decision making. The variety and complexity of current farm management systems have slowed the commercial application of computer simulation. It is currently possible to download spreadsheets for farm financial decision making from a variety of university-related Internet sites. In the future it is likely that some form of Internet-based computer simulation program will be available for farm use.

Frequency of Disease in Dairy Cattle

An important factor that influences herd productivity is the amount and type of disease that the dairy herd experiences. The frequency of diseases of dairy cattle has been a topic of numerous research reports. Most reports have been either prospective or retrospective reports describing disease conditions on one or more commercial dairy herds. Virtually all studies have documented the relationship of disease to the production cycle of dairy animals and have noted the interrelationships among diseases and risk factors. Many of the reports have estimated the cost of disease, and some have estimated the cost of preventive measures. A number of reports conclude by summarizing performance targets and acceptable levels of disease for the reference population of herds in their studies. The information contained in these observational studies is an important component of the knowledge base of health management practitioners because the basis of disease control programs includes the following:

- Knowledge of the frequency of disease
- Information about the biological effect of disease
- Information on the effectiveness of various control procedures

It is important to note, however, that the information included in many of these studies is incomplete, and direct extrapolations of survey information to individual herds should be made cautiously. The design of the study can contribute to inaccuracy of disease estimates. Retrospective studies are generally based on retrieval of computerized records of some sort from either an official production recording system or on-farm computer software. These studies often lack a common case-definition for diseases and have the assumption that all diseases are diagnosed and recorded on an equal basis. Given that episodes of severe clinical disease are more memorable than episodes of mild disease, the likelihood of recall bias in these studies is high. Most studies that depend on producer estimates of disease, not surprisingly, have significantly lower estimates of disease compared with estimates derived from prospective studies.

Incidence rates in prospective studies are generally estimated based on routine recorded observations of the dairy producer and his or her veterinarian. The frequency of clinical disease is generally reported as either lactational incidence rates or percentages of the at-risk population affected. The term "lactational incidence rate" is generally defined as

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the number of cows with at least one occurrence of disease during a lactation divided by the number of cows at risk for the lactation, expressed as a percentage (Dohoo et al, 1983). Recommendations for uniform reporting of clinical diseases have been proposed (Kelton et al, 1998). For retrospective analysis using historical data, lactational incidence risk is recommended. For current analysis (such as herd health monitoring), a true incidence rate (number of cases of disease divided by number of cow-days at risk for disease) is recommended.

Most studies differentiate between new and recurrent cases, but the definition of a new case often varies considerably between studies. When referring to reported disease estimates, the practitioner should always make note of the definition of the population considered to be at risk since it can considerably influence the applicability of the disease estimate, especially if differential risks apply to the disease. A good example of differential risk is the consideration of the at-risk population for milk fever. Since the risk of milk fever is known to increase with parity (Dohoo et al, 1984), the acceptable (or "target") baseline rate of milk fever in a herd composed entirely of first lactation animals should be considerably lower than in a herd composed of older animals.

Practitioners should consider other herd- and animal-specific risk factors when assessing the performance of a health management program. Dohoo et al (1984) evaluated the effects of age, season, and sire on the occurrence of the common diseases of Holsteins in Ontario, Canada. There were linear increases with age observed for milk fever, mastitis requiring intramammary therapy only, cystic ovaries, and foot and leg problems. No consistent age patterns were found for retained placenta, reproductive tract infection, abomasal displacement, teat injuries, digestive disorders, and abortions.

Environmental conditions also influence the risk of disease occurrence and should be considered when setting goals for a herd. Heat stress influences health and reproductive performance. In the United States it is well known that the levels of clinical and subclinical mastitis increase during periods of hot and humid weather. Similar cyclical trends linking poor reproductive performance to periods of heat stress have been recognized recently, even in traditional Midwestern dairy regions.

Most studies report only incidence rates of common, easily diagnosed, clinical diseases such as mastitis, lameness, milk fever, retained placenta, or DA. The frequency of subclinical disease is much more difficult to discern. The cost of obtaining subclinical disease information is inflated by the need to use screening tests (such as culture or somatic cell counts for mastitis, or fecal culture or enzyme-linked immunosorbent assay tests for Johne's disease) for diagnosis. The lack of repeated testing leads to the reporting of prevalence rather than incidence for many subclinical diseases. Estimates of the frequency of sporadic or endemic infectious diseases (such as listeriosis, infectious bovine rhinotracheitis, or leptospirosis) are also sparse. There is zero tolerance for some diseases that have serious consequences for public health. The occurrence of even one case of BSE, brucellosis, rabies, or tuberculosis in areas thought to be free from those conditions is cause for immediate action by veterinarians and regulatory officials. Most national disease control programs depend on surveillance by local veterinary practitioners.

Within the constraints just noted, knowledge of the frequency of disease is important for the veterinary practitioner. Table 6-7 shows a summary of recent reports of disease frequency of adult dairy cows in commercial dairy herds. Whitaker et al (2000) monitored 340 herds in southern England between April 1998 and March 1999. The average herd size was 133 cows, and average milk production was 6620 kg. This study was prospective and used explicit case definitions for the diseases of interest. Type of housing was a risk factor for both mastitis and lameness. It is interesting to note that considerable variability was noted between farms for many conditions. The incidence rates for the lowest and highest quartile of herds were 1.0% and 21.0%, 13% and 70%, and 5.8% and 50.3% for assisted calvings, mastitis, and lameness, respectively.

Data was retrieved from on-farm computerized record systems supported by the Northeast DHI for two studies (Gröhn et al, 1995, 1998). Both retrospective studies were conducted in commercial herds composed primarily of Holsteins and located in New York. The lactational incidence of several common diseases was reported (Table 6-7). The herds tended to be large (mean herd size of 323 for Gröhn et al [1995]; median herd size of 500 for Gröhn et al [1998]) and high producing (mean milk yield was 10,265 kg for Gröhn et al, 1998). Estimates of some diseases (ketosis, DA) were similar between studies, but differences in lactational incidence were noted for mastitis, milk fever, and metritis. Mastitis was only recorded if it required treatment, so differences in treatment protocols and selective recall likely resulted in underreporting of this condition. The exclusion of primiparous animals from the first study (Gröhn et al, 1995) probably accounted for part of the observed differences. This study noted significant interrelationships between diseases. Milk fever, metritis, and abomasal disorders increased the risk of ketosis. Cows diagnosed with ketosis had twice the risk of metritis, and cows diagnosed with retained placenta had more than six times the risk of metritis compared with cows that did not experience these disorders. Retained placenta and ketosis were significant predictors of abomasal displacement. The effect of milk yield on the risk of disease was the primary objective of this study, but higher milk yield was not identified as a risk factor for any disease except mastitis and ovarian cyst. This finding supported earlier work (Dohoo et al, 1984; Erb, 1987) that found little evidence that high levels of milk production predispose dairy cows to diseases other than milk fever. High milk yield was not a risk factor for veterinary-assisted dystocia, retained placenta, metritis, cystic ovary, clinical milk fever, clinical ketosis, left-sided displacement of the abomasum, and clinical mastitis (Erb, 1987).

The relationship between milk yield and disease occurrence was also studied in Finnish Ayrshire cows (Rajala and Gröhn, 1998). This study relied on data from the Finnish health data recording system and followed cows that calved during 1993. Animals included in this study were from small farms (only 9.3% of the herds had 25 or more calvings during 1993) with moderate production levels (mean 305-day milk yield was 6715 kg). The study population by parity was 33.5% (parity 1), 23.8% (parity 2), 17.1% (parity 3), and 25.6% (parity 4+). In this population, increased milk yield was found to increase the risk of acute mastitis, ovarian cysts, and anestrus in older cows. Higher milk yield increased the risk of milk fever in parity 2 cows but not in other age groups.

The differences in results between studies of Finnish Ayrshires and New York Holsteins were attributed by the author to differences in farm size and management (Grohn, 2000). Confounding issues, such as the preferential retention of high-yielding cows in the herd, may contribute to the perception of a relationship between yield and disease. High-yielding cows are more likely to be retained within the dairy herd and to receive veterinary treatments if ill when compared with low producers (Grohn, 2000).

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TABLE 6-7

Estimates of Selected Diseases of Adult Cattle in Commercial Dairy Herds, 1990-2000

Study	Study Characteristics	Clinical Mastitis	Lameness	Milk Fever	Metritis	Retained Placenta	Dystocia	Displaced Abomasum	Ketosis
Whitaker et al (2000)	Prospective, 340 herds, 45,220 cows, England, 12 months	36.6% of cows	23.7% of cows	5.3%	NR*	NR	8.7%	NR	0.4%
Gröhn et al (1998)	Retrospective, 14 herds, 7523 cows, New York, 12 months	14.5% lactational incidence†	NR	0.9%	4.2%	9.5%	NR	5.3%	5.0%
Gröhn et al (1995)	Retrospective, 25 herds, 8070 multiparous cows, New York, 3.5 years	9.7 % lactational incidence	NR	1.6%	7.6%	7.4%	NR	6.3%	4.6%
NAHMS (1996)	Questionnaire, 2542 herds representative of U.S. dairy industry	13.4% of cows	10.5%	5.9%	NR	7.8%	NR	2.8%	NR
van Dorp et al (1999)	Retrospective, 32 herds, 12,471 lactations Canada, 3 years	7.3%‡	NR	1.4%	9.9%	1.9%	NR	0.9%	0.6%
Beaudeau et al (1995)	Prospective, 47 herds, 3589 cows, France, 4.5 years	25.8% of lactations	14.9%	7.5%	12.0%	10.5%	9.9%	NR	3.1%
Rajala and Gröhn (1998)	Retrospective, 2338 herds, 39,727 cows, Finland, 12 months	21.1% lactational incidence	2.3%	5.4%	3.2%	3.1%	2.1%	0.7%	4.9%
Esslemont et al (1996)	Retrospective, 90 herds, 13,680 cows, England, 12 months	20.6% of cows; 33.2 cases/ 100 cows	17.4% of cows; 24 cases/100 cows	7.7%	NR	3.6%	8.7%	NR	NR
Frei et al (1997)	Prospective, 113 herds, 2262 cows, Switzerland, 15 months	32.7 cases/ 100 cow-years	10.0 cases per 100 cow-years	8.2	37.2	9.5	2.4	NR	NR

NAHMS, National Animal Health Monitoring System.
*Not reported in the study.
†Number of cows with at least one occurrence of disease during a lactation divided by the number of cows at risk, expressed as a percentage.
‡Lactational incidence of first occurrence estimated from study data.

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Data collected from on-farm computers were used to describe the frequency of disease occurrence in registered Holstein herds located in British Columbia, Canada (van Dorp et al, 1999). The average herd size was 110 cows, and most cattle were housed in free stalls and fed a TMR. This study noted that most diseases occurred during the first 30 days of lactation and that the occurrence of early lactation disease tended to increase the risk of other diseases later in lactation. Udder edema was more common in first lactation animals and was a risk factor for mastitis, metritis, and cystic ovaries. Milk fever was directly associated with the risk of DAs. Seasonal effects were shown for the risk of mastitis, retained placenta, metritis, cystic ovaries, ketosis, and foot rot.

It is interesting to compare the occurrence of disease among vastly different production systems. Esslemont and Kossaibati (1996) and Frei et al (1997) reported disease occurrence in selected herds in England and Switzerland. The reported rates of mastitis and milk fever were remarkably close even though the herd populations varied significantly. The average herd size and milk yield was 152 cows and 6000 L for the English herds compared with 15.5 cows and 4400 kg (estimated) for the herds included in the Swiss study.

A number of well-known risk factors for disease have been defined by earlier studies. Bendixen et al (1986) reported risk factors for dystocia in Swedish red and white (SRB) and Swedish Friesian breeds (SLB). Parity (first parity animals had a higher risk), breed (SLB had a higher risk than SRB), sex (male calves had a higher risk), and previous history of dystocia were among the risk factors that were identified. Bendixen et al (1987) also identified an increased risk of retained placenta associated with breed, age, occurrence of milk fever, dystocia, twinning, and the birth of male calves.

The recurrence of disease was reported for 8782 pairs of lactations in Israeli Holsteins that were followed for 8 years (Markusfeld, 1987, 1990). Annual milk yield in this population raged from 7000 to 10,000 kg. The crude risk ratio for recurrence was 2.1 for twinning, 16.7 for milk fever, 3.1 for ketonuria, 1.7 for retained placenta, and 1.7 for metritis.

The frequency of common diseases of adult dairy cattle was reviewed through a complete literature search of articles that spanned 26 years (Kelton et al, 1998). The median and range of lactational incidences were reported: milk fever (6.5%; 0.03% to 22.3%), ketosis (4.8%; 1.3% to 18.3%), left DA (1.7%; 0.3% to 6.3%), cystic ovarian disease (8.0%; 1.0% to 16.1%), lameness (7.0%; 1.8% to 30.0%), and clinical mastitis (14.2%; 1.7% to 54.6%).

The dairy practitioner requires knowledge about the frequency of calfhood morbidity and mortality. The National Dairy Heifer Evaluation Project, sponsored by NAHMS, reported retrospective data on 1811 dairy farms and prospective surveillance data on 921 U.S. dairy farms (NAHMS, 1996). Preweaning calf mortality was 8.4% and 6.8% for the prospective and retrospective data, respectively. Diarrhea accounted for 52.2% of mortality, followed by respiratory disease (21.3%), trauma (2.4%), joint and navel disease (2.2%), and other or unknown causes (21.9%). Morbidity during the first 3 weeks of life was attributed to pneumonia (25%), diarrhea (29%), and umbilical disease (29%), according to data obtained from 410 dairy calves born in 1990 on 18 commercial dairy herds in New York (Virtala et al, 1996).

In summary, baseline measures of disease for a variety of management systems have been reported. This knowledge is an important starting point for the establishment of health and performance targets on dairy farms. The dairy practitioner is responsible for integrating knowledge of the specific dairy herd farm with existing knowledge about disease to derive appropriate health management programs for the farms that he or she serves.

Influence of Disease on Productivity

The effects of disease on animal productivity have been described extensively (Morris, 1997). Alterations at the individual animal level include reductions in the nutritional, metabolic, and physiological status of the diseased animal leading to reduced productive capabilities (Fig. 6-5). These reductions initially occur at the individual animal level but can ultimately lead to reductions in productivity of the entire herd. The effects of disease on productivity can be direct (such as mastitis causing a profound reduction in milk yield) or indirect (such as reduced locomotor ability leading to reduced feed intake, thus causing reduced milk yield). The interrelationship between diseases occurring in early lactation can also lead to a cascading effect that ultimately leads to lowered productivity. Data obtained over a 12-month period from 1374 Holstein lactations in 31 commercial dairy herds in New York State demonstrated that periparturient disorders often occur as a complex (Curtis et al, 1985). For example, cows diagnosed with parturient paresis were at increased risk of retained placenta, complicated ketosis, and mastitis. Cows with veterinary-assisted dystocia and retained placenta were at increased risk of metritis.

Only short-term direct effects on production are usually considered in most studies of the effects of clinical disease on productivity. The most documented direct effect is the effect of mastitis on milk yield. One review of this relationship examined 20 studies composed of at least 250 lactations per study (Hortet and Seegers, 1998a). This study concluded that a single case of clinical mastitis resulted in a milk yield loss of 300 to 400 kg/lactation. A high variability of loss was noted; approximately 40% of clinical cases were associated with negligible loss, 30% of clinical cases led to a loss of 150 to 250 kg, and 30% of clinical cases led to losses of 950 to 1050 kg. Milk yield losses of 200 to 300 kg/lactation were noted for primiparous cows. This study also noted that mastitis cases occurring in early lactation were associated with higher losses (450 to 550 kg) compared with cases that occurred later.

The effect on the lactation curve of diseases that occur in early lactation is an important reason for the development of sound preventive medicine programs for early lactation. An extremely difficult dystocia was demonstrated to reduce milk, fat, and protein yields by 704 kg, 24 kg, and 21 kg, respectively, compared with yields of cows that calved without assistance (Dematawewa and Berger, 1997). Significant reductions (6% to 7%) of peak milk yield were noted in lactations in which a cow had a retained placenta or ketosis (Rowlands and Lucey, 1986). In cows with ketosis, the decline in milk yield was slower in later lactation and no overall difference in 305-day milk yields was noted. The lactation curve is determined by initial production, peak milk yield, and persistency. Low initial production may reflect poor nutrition, inadequate management, poor dry cow management, or periparturient disease problems. The slope of the curve following peak production is generally referred to as persistency. Persistency can be defined as the extent to which peak milk production is maintained. As discussed earlier, innate persistency is not highly variable, so a reduction in peak milk yield can have long-lasting effects on productivity. Heifer lactations tend to be more persistent than those of older cows. Cows from higher producing herds have high peak milk yields and are more persistent than lower producing cows. Adverse environmental conditions (especially heat stress) can also alter the shape of the lactation curve.

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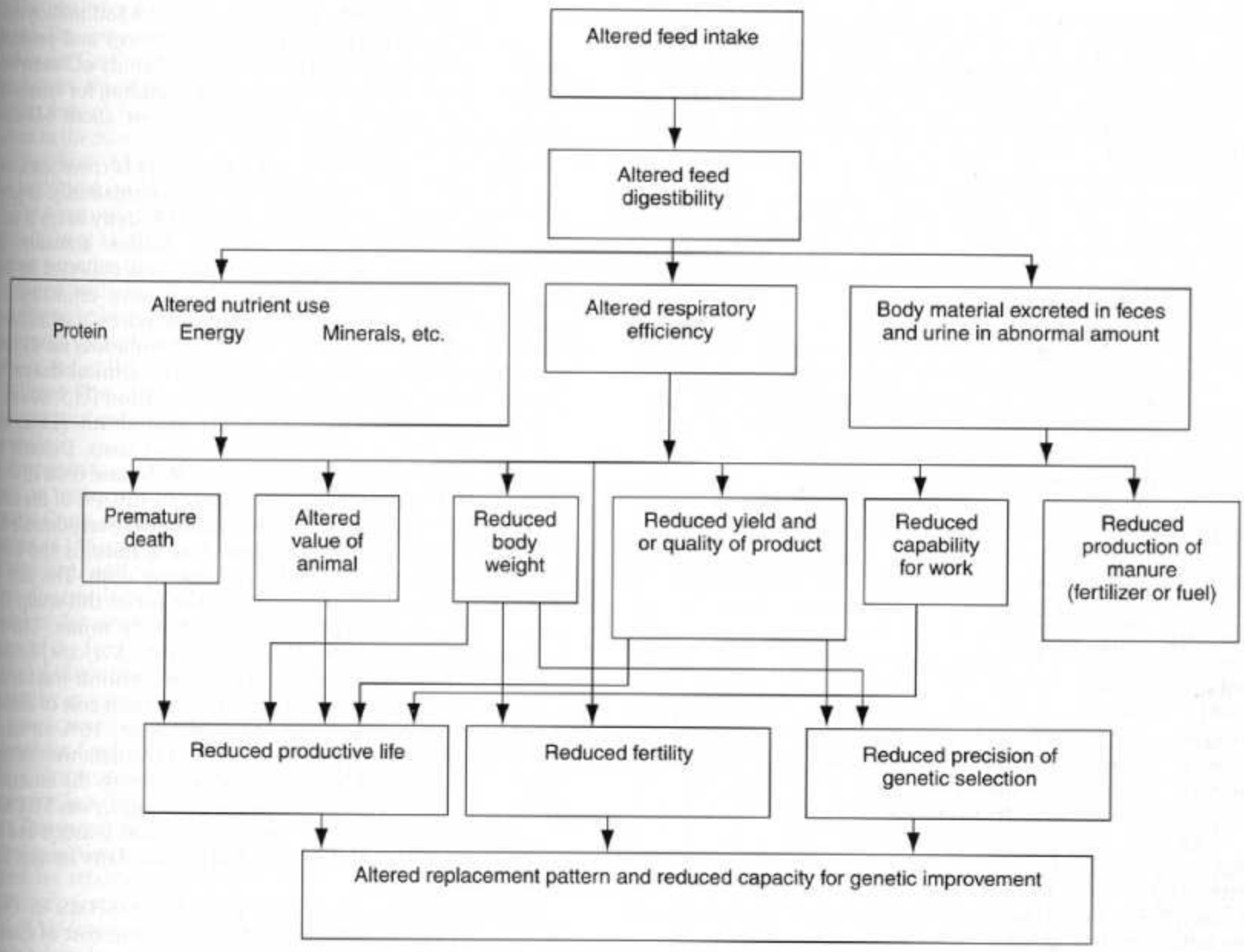

FIG. 6-5 Effect of disease on productivity. (Adapted from Morris RS: How economically important is animal disease and why? In Dijkjuizen AA, Morris RS: *Animal health economics*, Sydney South, Australia, 1997, University of Sydney.)

The method of production recording has an influence of estimates of production loss caused by disease. Automatic milk meters that record daily milk production for each cow enable the detection of deviations from normal performance. Through the use of daily milk weights, subclinical disease can be detected 2 or more weeks before its clinical appearance (Lucey et al, 1986). Significant differences in milk yield have been detected between 1 week before and 1 week after clinical diagnoses were observed for ketosis, hypomagnesemia, lameness, and mastitis cases after peak milk yield. Milk yield declined for as long as 2 to 4 weeks before diagnosis of disease. Total losses in milk yield associated with ketosis or hypomagnesemia were as high as 60 to 70 kg. Daily milk losses varying between 1.0 to 5.3 kg have been found for Finnish Ayrshires affected with clinical mastitis, ketosis, milk fever, and lameness (Grohn, 2000). In some instances, total lactational yields were not affected by short-term reductions in daily yield.

A number of common diseases of dairy cattle have been shown to influence lactational milk yields. A study of Holstein cows in Ontario indicated that milk fever, retained placenta, abortion, and other diseases were detrimental to milk production (Bigras-Poulin et al, 1990). Metritis and ovarian cysts had a positive effect on concurrent milk production because of increased number of days of lactation. A positive effect of diagnosis of ovarian cysts on total milk yield in the concurrent lactation was followed by a detrimental effect on milk production in the subsequent lactation. Retained placenta caused a 7% reduction of 305-day milk yields in one study composed of 1594 lactations occurring in 732 British Friesian, Ayrshire, and Holstein crossbred cows (Rowlands and Lucey, 1986). This study did not note any significant associations among hypocalcemia, hypomagnesemia, dystocia, or endometritis and milk yield.

Studies about the relationship between lameness and milk yield have been equivocal. Increased and decreased milk yields have been associated with lesions in specific regions of the hoof. A tendency for increased lameness in high-yielding cows has been noted in some studies. While it seems reasonable that lameness is associated with reduced milk yield, continued research is needed to fully explain the relationship.

Losses resulting from subclinical disease are not as apparent as losses from clinical disease but are often considerable. The best described relationship between subclinical disease and productivity is the effect of subclinical mastitis on milk yield. A review of 19 papers concluded that each twofold increase in SCC above 50,000 cells/ml caused a loss of 0.4 and 0.6 kg milk/day in primiparous and multiparous cows, respectively (Hortet and Seegers, 1998b). Total lactational milk yields were estimated to be reduced

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by 80 kg for primiparous and 120 kg for multiparous for each twofold increase in the geometric mean SCC over 50,000 cells/ml. Other subclinical diseases have also been related to reduced productivity. Subclinical Johne's disease is estimated to reduce lifetime milk production by 3926 kg (Hutchinson, 1996). Over 40% of the reduced production occurred during the final lactation of affected cows.

Veterinary literature largely supports the concept that many clinical and subclinical diseases adversely affect milk yield. Improved productivity of the dairy herd is a strong incentive for many dairy producers to participate in health and production management programs.

The ability to successfully reproduce is a necessary component of productivity. Diseases that delay or prohibit conception have a negative effect on herd productivity by prolonging the time that cows spend in lower producing stages of lactation, by reducing the number of offspring for replacements or for sale and by increasing the likelihood that the animal will be culled prematurely. Many reasons for declining conception rates have been considered. Some genetic studies have reported antagonistic correlations between production traits and health disorders, implying that selection for yield causes deterioration in health and fertility (Pryce et al, 1998). Several diseases have been associated with conception rates. The likelihood of conception was reduced by 14%, 15%, and 21% for cows that experienced retained placenta, metritis, or ovarian cysts, respectively (Eicker et al, 1996). Mastitis, metritis, and ovarian cysts reduced the likelihood of cattle being bred for the first time. Postpartum diseases that prolong negative energy balance in early lactation probably also have a negative effect on reproductive performance through alterations in hormonal activities.

The effect of disease on longevity has been investigated. A large proportion of cow culling is considered involuntary (driven by disease, injury, or death) rather than for reasons of low production. The premature removal of a cow from the herd reduces lifetime milk yield. Reproductive failure and mastitis are consistently recorded as the top two reasons for culling. A culling rate of 22.1% was recorded for 340 British dairy herds (Whitaker et al, 2000). The top four reasons recorded for culling were infertility (25.3%), mastitis (16.3%), lameness (7.7%), and age (16.7%). A separate British study of 50 dairy herds recorded an overall culling rate of 23.8% (Esslemont and Kossaibati, 1997). Poor fertility accounted for 36.5% of removals followed by management policy (11.5%), mastitis (10.1%), BSE (7.4%), and lameness (5.6%).

In France, the probability of a cow being culled was higher for cows that experienced mastitis, teat injuries, or udder disease (Beaudeau et al, 1995). Cows with metritis or cows experiencing early abortion also had poor survival. In New York, metritis did not influence culling, but mastitis, milk fever, retained placenta, DAs, ketosis, and ovarian cysts were found to affect culling significantly (Gröhn et al, 1998).

In general, disease influences productivity by reducing milk yields, decreasing reproductive performance, and limiting the length of productive life. Veterinary practitioners involved in production and health management programs are likely to have a considerable opportunity to improve the productivity of the farms that they service.

Estimate of the Costs of Dairy Cattle Diseases

The aggregate and individual cost of disease has been estimated with varying precision at a number of levels. Disease costs include outlays for veterinary services and products and disease-related reductions in productivity. The cost of veterinary services and products is more easily estimated than the cost of reduced productivity. In 1993, U.S. producers spent an estimated aggregate sum of $580 million dollars (about $60/cow) on veterinary services and products (USDA, 1993). A smaller, more detailed study of Pennsylvania producers estimated that annual spending for veterinary supplies and services was $2606/farm or about $43/cow from 1986 to 1990 (Miller et al, 1993).

When the cost of reduced productivity is considered, estimates of the cost of disease increase dramatically. In general the aggregate cost of disease for U.S. dairy herds is estimated to exceed several billion dollars annually. In California, disease and economic data was collected for the NAHMS (Sischo et al, 1990). Costs were estimated for death, culling, weight loss, veterinary services, medication, disposal, labor, calves born dead, and milk loss on 43 randomly selected dairy herds. The cost of clinical disease in California was estimated to be $1.75 million (U.S. dollars) or $112/cow/year. Culling (52%) and death (24%) accounted for a large proportion of total costs. Diseases of adult cows accounted for 93% of total disease costs in contrast to calf disease, which represented only 4% of the total disease costs. Diarrhea and pneumonia were responsible for 86% of costs of calf diseases, and clinical mastitis and infertility accounted for 53% of cow disease costs. The cost of subclinical disease was not accounted for in this study. The cost of disease prevention was relatively minor. The 43 herds in the study spent about $172,000 ($11/cow) for disease prevention. Most of the cost of prevention was for the purchase of drugs and biologics. Of the total cost of disease prevention, 55% was spent on medication, 16% for labor and 29% for veterinary services. When the data were extrapolated to the entire California dairy industry, the estimated cost of clinical disease and disease prevention was $118 million for the 1-year period studied. Clinical mastitis and infertility were estimated to cost California dairy farmers $53 million a year.

Economic data were collected for NAHMS in Ohio (Miller and Dorn, 1990). In this study the cost of disease was estimated to be about $152 per cow-year, and the cost of prevention was an additional $21 per cow-year. The proportion of costs attributable to specific diseases was mastitis (26%), infertility (13%), pneumonia (5%), lameness (5%), dystocia (5%), milk fever (4%), left displacement of the abomasums (4%), and death (3%). Most of the cost of disease occurrence was due to deaths, culling, and stillbirths followed by milk loss, drugs, biologics and veterinary services, body weight loss, labor, and carcass disposal. Most of the prevention costs were for drugs and biologics, followed by veterinary services and labor input. When preventive expenditures not attributed to a specific disease were included, the annual total health-related cost was $188/cow.

Estimates of the costs of specific diseases have been generated, particularly for mastitis. Using unpublished NAHMS data, Wells et al (1998) estimated the annual aggregated sum of individual producer costs of mastitis for U.S. producers to be $1.5 to $2 billion. The loss from subclinical mastitis was estimated to be $960 million. Clinical mastitis was estimated to cost California dairy producers $27 million annually (Sischo et al, 1990). The cost of a case of clinical mastitis has been estimated at $104/case for California producers (Sischo et al, 1990) and $107/case for Ohio producers (Hoblet et al, 1991). The cost of clinical mastitis was estimated for both mild ($139/case*) and severe ($433/case*) mastitis in English dairy herds (Kossaibati and Esslemont, 1997). Most of the losses for clinical mastitis are attributable to discarded milk.

*Converted from pounds sterling at $1.40 U.S. dollars per pound.

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The cost of a number of other diseases has been estimated. The cost of a DA was estimated to be about $250 to $400/case (Geishauser et al, 2000). Losses consisted of treatment costs, discarded milk, decreased milk yield, reduced fertility, loss of body weight, and increased risk of culling. Losses to the North American dairy industry were estimated to range from $55 million to $220 million depending on the lactational incidence rate.

The economic impact of Johne's disease has been estimated (Ott et al, 1999). Herds that were positive for Johne's disease experienced an economic loss of almost $100/cow compared with herds without Johne's disease. Most loss was due to reduced milk production and increased cow replacement costs. When the prevalence of Johne's exceeded 10% of the cull cows, economic losses were greater than $200/cow. The cost of Johne's disease to the U.S. dairy industry was estimated at $200 million to $250 million annually.

Productivity, prevention, and treatment losses were used to estimate the cost of several diseases (Guard, 1994). Costs were estimated for milk fever ($335/case), ketosis ($145/case), left displacement of the abomasum ($340/case), and lameness ($302/case). The occurrence of these diseases is related to management issues such as the design of the stalls or barns, manure handling, and the adequacy of the feed formulation and delivery system. The incidence of these diseases is minimized in herds with sound preventive management practices.

Losses caused by a number of production diseases were estimated for English dairy herds (Kossaibati and Esslemont, 1997). This study used a survey of 10 veterinary practices to determine fees, treatment costs, and typical treatment protocols. This survey also included costs for farm labor and estimated reductions in yield. The cost (in U.S. dollars) was estimated for retained placenta ($416/case), mild milk fever ($70/case), severe milk fever ($216/case), and digital lameness ($336/case). This study estimated that ill health cost English dairy farmers approximately $8825/100 cows/year.

It is apparent that disease is a considerable cost to the dairy industry. Studies have consistently indicated that much more money is expended on disease treatment than on prevention. Prevention of disease is cost effective. One study demonstrated that each marginal dollar spent on veterinary services and supplies returned $3.22 in additional revenue from milk production (Miller and McSweeny, 1993). The challenge for the dairy practitioner is to effectively communicate and market preventive health care practices to their clients. Current and developing trends within the dairy industry will make the need for effective preventive health management programs even more acute. Fewer herds are truly isolated and more animals are housed in larger units, thus the risk of acquiring infectious disease is increasing. In addition, the cost of subclinical disease has not been recognized fully. Defining and implementing practices to promote healthy and productive cattle should be the goal of every dairy veterinarian.

Other Potential Causes of Economic Loss in Dairy Herds

The dairy practitioner should be concerned about other, less obvious potential losses than those just described. A number of diseases of dairy cattle have zoonotic potential (Table 6-6). The loss of public confidence in the purity and integrity of the food supply could be catastrophic for the dairy industry. The European experiences with BSE should be considered when farm practices and regulatory procedures are reviewed. The linking of new variant Creutzfeldt-Jacob disease (nvCJD) with the ingestion of beef has devastated the British beef industry and cost agriculture its' credibility with European consumers. While North America has not experienced BSE, other food safety and welfare issues could reduce the public confidence in the dairy industry. Food safety is not an issue that most producers spend much time worrying about. However, human pathogens such as *Listeria monocytogenes*, *Salmonella* spp., and *Escherichia coli* O157:H7 are known inhabitants of the dairy ecosystem. *Listeria* and *Salmonella* are pathogenic in cattle and can be shed in milk. They are regularly found in unpasteurized bulk tank milk, and exposure can occur through ingestion of raw milk or raw milk products. *Salmonella* and *E. coli* O157:H7 are common fecal contaminants of carcasses. One role of the veterinary practitioner is to educate farmers about food safety and to promote practices to ensure that food products are derived from healthy cattle.

Another emerging issue is the change in societal ethics regarding animal welfare. Consumers are increasingly interested in the conditions in which animals are raised and are especially concerned about perceived suffering. Although the dairy industry is generally regarded positively, the handling of recumbent cattle, housing of veal calves, and concern about humane slaughter practices are issues that animal activists are pursuing. A proactive approach by everyone involved in the dairy industry is needed to ensure that animals are handled humanely throughout their entire productive lifespan.

Monitoring the Frequency and Economic Impact of Dairy Cattle Diseases

The vast majority of animal disease monitoring is done on an individual herd basis by the local practitioner working with on-farm record systems. About 60% of U.S. dairy herds belong to production reporting programs such as DHI. The primary focus of these programs is to collect and collate information to be used in genetic proofs of dairy sires. Although genetic progress and production is assessed and compared across herds through the use of DHI systems, a comprehensive system to collect and collate health information has not been devised. On-farm disease reporting is tremendously difficult because of issues such as case definition, the recording of recurrent disease, and the determination of at-risk populations. Many farms have only handwritten record systems, and some do not identify all the animals with unique identification. Attempting to introduce monitoring programs in herds that are lacking proper cow identification or record systems can be extremely frustrating. Dairy record systems are addressed in Chapters 3 and 7, but the importance of a complete record system cannot be overemphasized. The existence of a record system does not always lead to information that is useful in making management decisions. For a record system to be used, there must be a method to routinely summarize pertinent production and disease indices and a forum for discussions between the practitioner and the farmer. Ideally, a method of benchmarking herd performance against peers should be available. In some instances, data from regional or national databases can be used if local data are not available.

Most countries with developed dairy industries have some sort of surveillance system based on collecting farm level data from a selection of farms and extrapolating that information to the U.S. herds. In the United States, NAHMS is an active surveillance system, based at the farm level, with the goal of generating data for statistically valid estimates of incidence and prevalence and costs of various diseases of livestock and poultry (Kaneene and Hurd, 1990; Hurd and Kaneene, 1990). NAHMS data are useful for identifying overall industry trends but are generally too

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far removed from an individual farm to be used as benchmarking data.

In Canada, a variety of farm surveillance programs are in use. The Animal Productivity and Health Information Network (APHIN) was established at the Atlantic Veterinary College in Charlottetown, Prince Edward Island (Dohoo, 1992). The Quebec Dairy Herds Health Improvement (ASTLQ) Project (Bouchard et al, 1997) was established with the following objectives:

1. To build a data bank in animal health for dairy cattle.
2. From the data bank to calculate health indices and associations between reproduction, production, disease, and culling.
3. To compare herds with regard to the indices calculated and to classify them as "healthy" or "sick."
4. To create tools to calculate and interpret the indices.

The programs just mentioned have been useful tools for farmers, veterinarians, and other consultants and have contributed to the enhanced decision making for farms served by the programs. It is likely that Internet-based database systems that are constantly accessible to farmers and their consultants will replace most existing systems in the near future. Internet-based systems have an advantage in allowing data entry on the farm and allow for multiple access to real-time data.

The access to farm-based information is the foundation of a sound production management and health program. The ability to access farm data quickly and easily enhances the likelihood that realistic data will be used in the problem-solving and decision-making process. As local systems become available, farm benchmarking can be a valuable tool for motivation of dairy clients.

ROLE OF THE HEALTH MANAGEMENT PROGRAM

The adoption of preventive health care programs for dairy herds has been promoted for at least 25 years. The desire to continually improve efficiency and the recognition of disease as a contributor to reduced productivity are the primary reasons that many herds have adopted health management programs. The universal goal of health management programs should be to assure the optimum care and well being of the dairy animals and therefore to reduce losses in productivity caused by disease and management errors. The provision of these conditions is expected to lead to profitability for the dairy business and ultimately to contribute to the well being of the farm owner and employees. The veterinarian delivering health management programs will likely fill a variety of roles depending on the interests, expertise, and availability of other local experts. Multiple resources such as specialized extension services, industry personnel, and private consultants are available to dairy producers in some regions. In other regions, the dairy industry infrastructure may not be as developed and the local veterinary practice may be the primary provider of many services. Regardless of available resources, the scope of the dairy health management program can be extensive (Fig. 6-6). In some instances the veterinary practitioner may be both the initiator and the deliverer of services. A typical example would be an assessment of herd reproductive status leading to the adoption of a reproductive management program. In other instances the veterinary practitioner may serve as the coordinator of services from specialized consultants or industry personnel. An example of such a role is when the veterinarian routinely reviews feed delivery programs of rations developed by a specialized dairy nutritionist. Some veterinarians also play the role of "animal experts" in health management programs when the farmer deals with non-farm-based consultants such as bankers, architects, or environmental assessment personnel.

Virtually all dairy farms have some contact with veterinarians. Veterinarians are a well-regarded source of information for health care decisions. Of dairy producers surveyed for the NAHMS Dairy '96 study, 78% regarded the veterinarian as a very important source of information for health care decisions. Only 2.3% of producers considered veterinarians as not being an important source of health care information. Nutritionists were the next most important source of health care information, but only 39% of producers considered them to be very important and 27% considered them as not being an important source of health care information. Veterinarians are a frequent presence on dairy farms, and the frequency of farm visits increases as herd size increases (Fig. 6-7). The frequent presence of veterinary practitioners on dairy farms is unique among agricultural professionals and gives veterinarians an advantage in understanding farm processes and personnel.

Although health management programs have been promoted for a number of years, the primary use of veterinarians by dairy producers continues to be individual animal care. In the NAHMS survey of dairy producers, the top five reasons veterinarians visited farms were: (1) individual animal diagnosis and treatment (listed by 96% of respondents); (2) provision of drugs and vaccines (88%); (3) vaccination consultation and services (77%); (4) reproduction consultation and services (74%); and (5) herd diagnostic services (51%). Only 27% of producers listed nutritional consultation and only 14% listed housing or ventilation as reasons for veterinary visits.

Considerable evidence exists that the delivery of health management programs remains a growth area for many dairy practices. The adoption of many routine preventive health care practices by dairy farms continues to be below expectations. Adoption rates of a number of practices were reported for U.S. herds (NAHMS, 1996). In spite of almost universal promotion of many routine mastitis control procedures for over 25 years, only 77%, 58%, and 89% of farms reported the use of universal dry cow therapy, premilking teat dipping, and postmilking teat dipping, respectively. Only 71% of farms reported that all antibiotic treatments were recorded. Universally recommended practices, such as dipping navels of newborn calves and vaccination against BVD, were reported by only 53% and 71%, respectively, of overall survey respondents.

A survey of veterinarian and producer perceptions regarding herd health services was performed in Saskatchewan, Canada (Giger et al, 1994). Farmers that identified themselves as participating in herd health programs had more frequent, regularly scheduled visits by veterinarians to their farms compared with herds that did not participate in herd health programs. Producers that participated in herd health programs indicated that they received more advice and services in areas of reproduction, nutrition, and mastitis control compared with farmers who were not enrolled in a herd health program. Reproductive services were considered to be the major component of the herd health program. This finding agrees with studies performed earlier (Goodger and Ruppanner, 1982; Wise, 1987) showing that reproductive services were the primary component of herd health programs. There is some indication that a gap exists between the perception of services offered by veterinary clinics and the perception of services received by producers. In the Saskatchewan survey the veterinary clinics indicated that they offered "fairly comprehensive" nutritional services, whereas the producers indicated that they only "occasionally" received advice on nutrition. A high proportion of farmers (60%) indicated that

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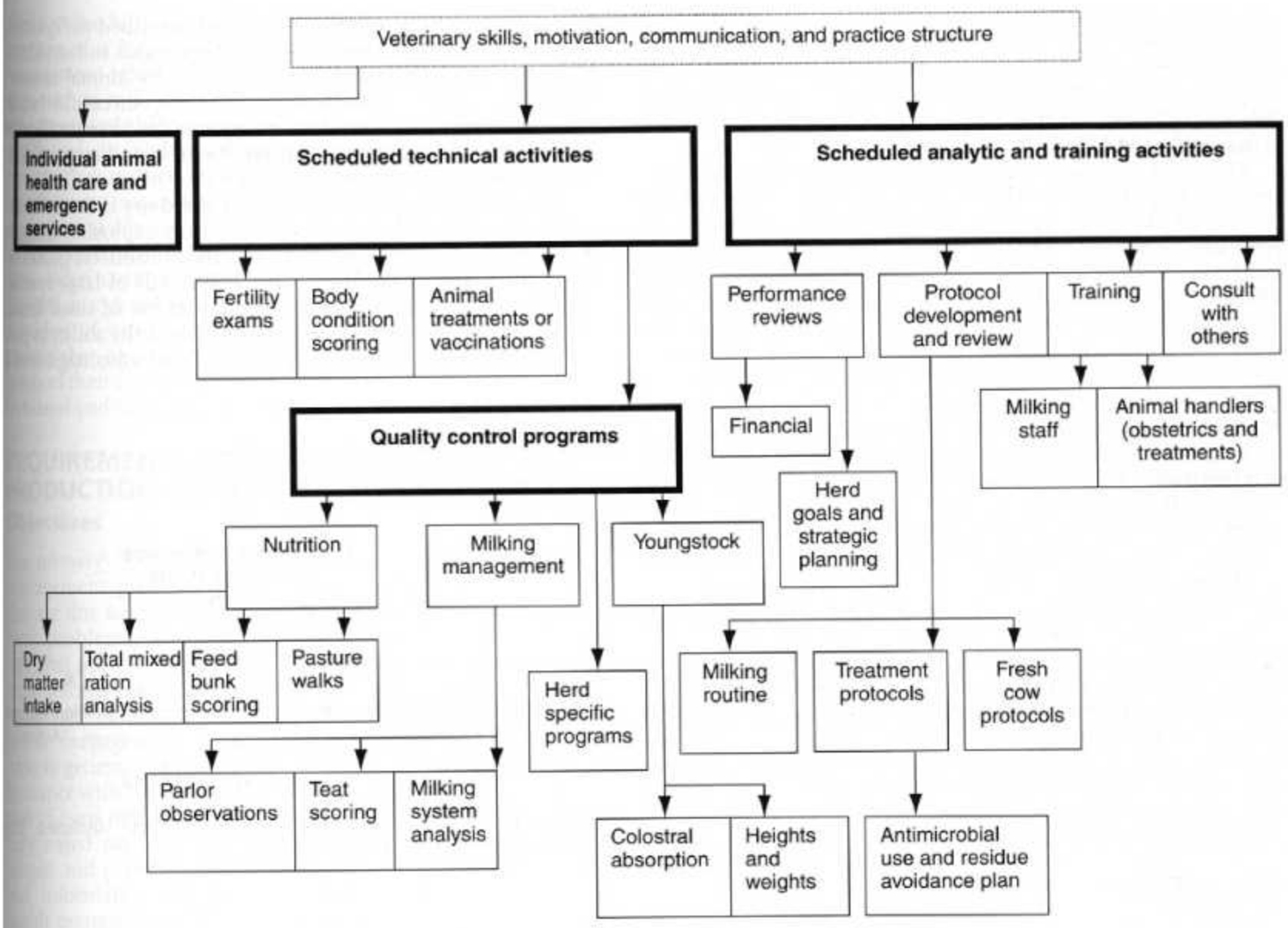

FIG. 6-6 Components of a dairy health and production management program.

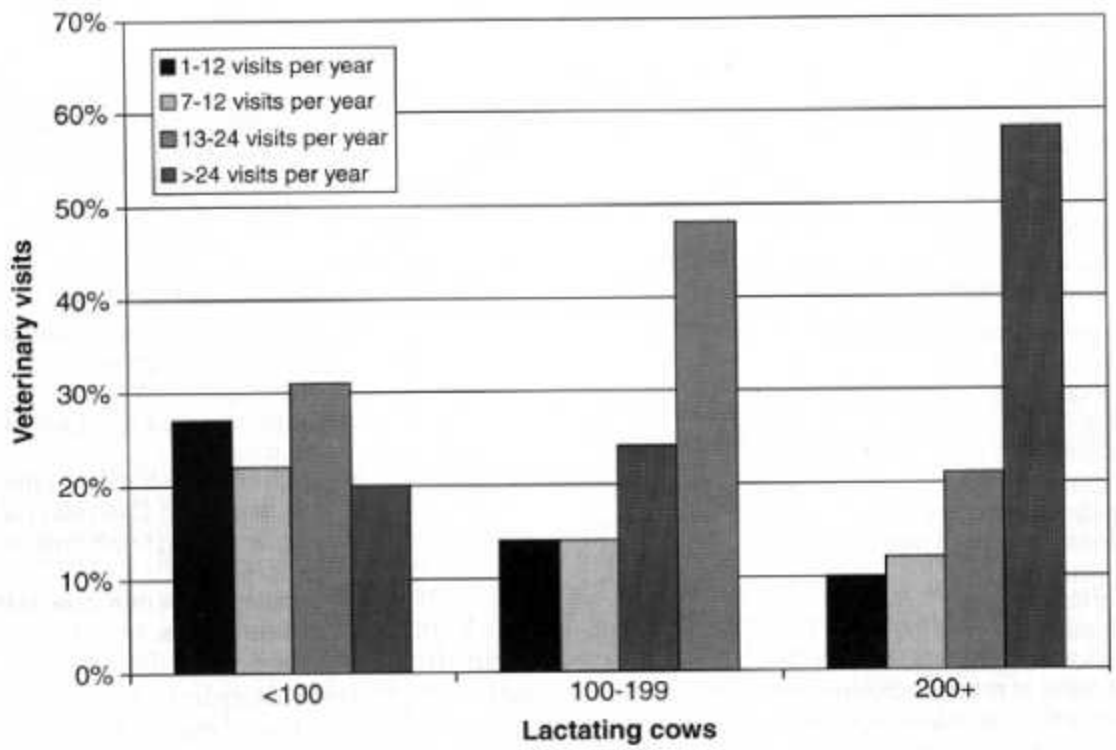

FIG. 6-7 Frequency of veterinary visits to dairy farms by herd size.

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their veterinarian was rarely or never involved in the analysis of herd records. This finding agrees with a survey of progressive Wisconsin dairy farmers involved in a milk quality management program (Ruegg, 2000). Only 40% of the herds in this survey indicated that they routinely consulted their veterinarians regarding milk quality.

The slow uptake of health management programs appears to be an issue in developed dairy regions throughout the world. In the United Kingdom a survey of veterinary practices indicated that the practice operators considered herd health programs very beneficial, but only about a third of the practices were offering them (Wassell and Esslemont, 1992). The lack of farmer motivation was the primary reasons listed for the lack of adoption of these programs. Farms were more likely to adopt herd health programs when a disease or fertility problem existed on their farm. These findings emphasize the importance of communication and marketing skills as a component of the skill set of veterinarians involved in health management programs.

A health management feedback cycle consists of an interrelated series of events and decisions based on the acquisition of performance data, the analysis of the current status of the herd, and resulting actions to correct or prevent problems. The health management cycle has been described (Fig. 6-8; Fetrow, 1993). A major limitation to the success of many health management programs is a breakdown in consistent implementation of health management plans. One reason that implementation may be difficult is that the successful execution of health management plans is often dependent on the motivation of others rather than of direct actions of the veterinarian themselves (Fig. 6-9). The ability to convince and motivate dairy producers and employees is a function of marketing and effective communication of health management programs. Marketing has been described as "synchronizing the business aspects of his or her goods and services so that they are understood and desired by animal owners" (Herrick, 1989). Veterinarians offering successful health management and production programs are often excellent at understanding the needs of their clientele and communicating the success of the programs that they offer.

The continuing restructuring of the dairy industry in developed countries and the information explosion through the Internet have changed the way that producers gather information and make decisions. The needs of large specialized dairy farmers are different than those of small farms. Large farms tend to have specialized labor, the ability to purchase large volumes of supplies at a cost advantage, and

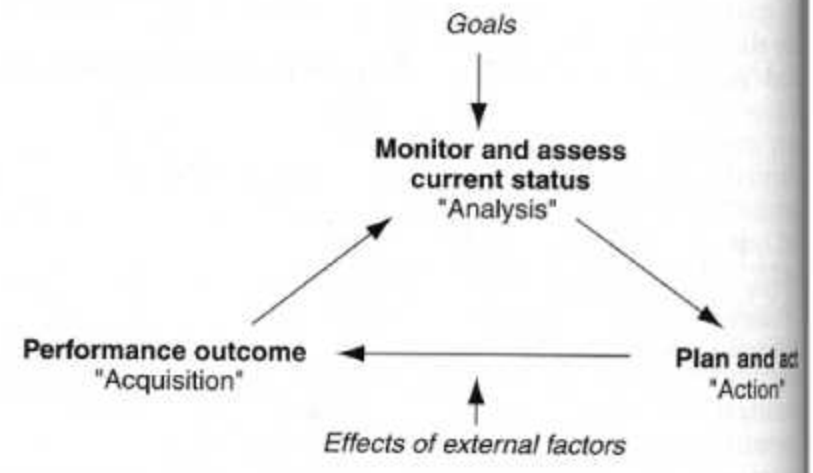

FIG. 6-8 Health management feedback cycle. (Adapted from Fetrow J: *Bov Prac* 27:88-101, 1993.)

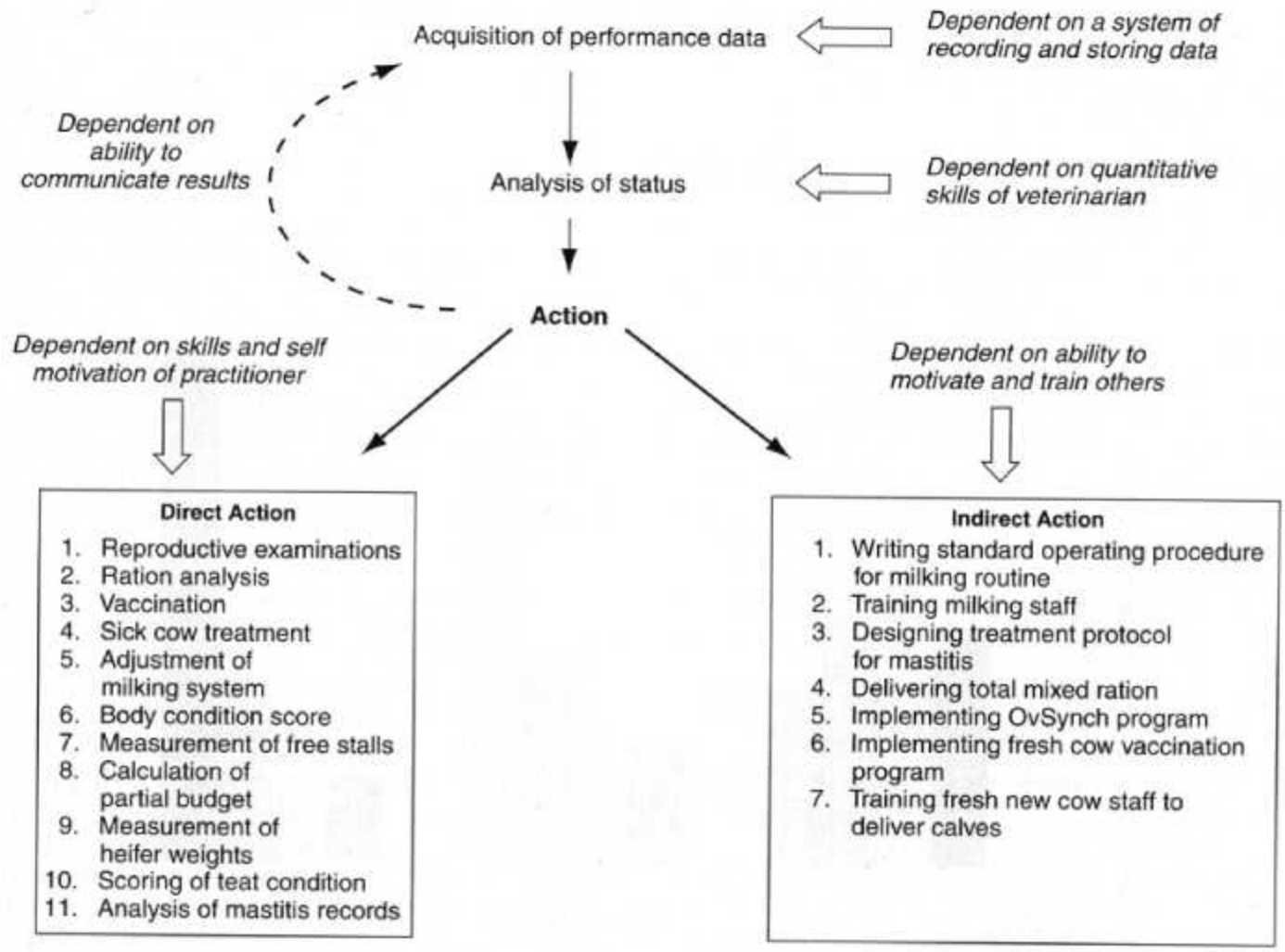

FIG. 6-9 Implementation of dairy health management programs.

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need for scheduling and consistency (Nordlund, 1998). The operator of a large dairy generally spends more time on management-related functions rather than labor-oriented tasks such as milking. These large producers have considerable access to information about management and animal health and are likely to directly contact recognized subject experts when specific needs arise. Large dairy producers also have frequent contact with industry representatives, including technical service veterinarians and professional nutritionists employed by large feed and pharmaceutical companies. Veterinarians who provide only clinical services directed at individual cows risk becoming marginalized as providers of information and management advice. Veterinarians that have developed specialized skills to meet the needs of their clients are extremely valuable as purveyors of unbiased and objective advice.

REQUIREMENTS OF A DAIRY HEALTH AND PRODUCTION MANAGEMENT PROGRAM

Objectives

The primary objective of a dairy health and production management program is to minimize productivity losses that are due to disease, nutritional disorders, and management problems. An additional objective should be to ensure that preventive health and management practices are economically justified. It is probably safe to assume that all herds can benefit from biologically and fiscally sound health management programs. The health management cycle is generally predicated on comparisons of herd performance with predetermined performance goals. The selection of herd performance goals should be considered carefully based on the farm environment, motivation of the farmer, and presence of adequate resources (labor, capital, and information sources) to succeed. The structure of health management programs is generally unique to each farm but is minimally composed of scheduled herd visits that are usually a combination of routine reproductive examinations, review of selected herd performance records, and decisions and actions related to specific herd management issues.

Targets of Performance

A number of widely recognized performance targets have evolved as industry standards over the years. Examples of such targets are shown in Table 6-5, and more specific descriptions of acceptable performance are explained in individual chapters of this book. The performance targets reflect herd standards of performance that are perceived as indicators of successful herd management. Although there is tremendous value in recognizing these standards, the dairy practitioner needs a thorough understanding of the strengths and limitations of these targets.

Performance targets are useful as comparison values for herd performance and as a starting point to initiate discussions about potential areas for improvement. To use a performance target, it is necessary for a herd to have a record system that allows for the generation of comparable herd indices. The veterinarian must also understand how the targets were calculated and must be able to define the appropriate at-risk population to include in the statistic. An understanding of the inherent distribution and biologic variation of the value is also important. In many instances, performance targets have been calculated as arithmetic averages. Arithmetic averages are useful indicators of herd performance when the contributing data are normally distributed and have a reasonable degree of variation. Many production data (such as milk, fat, and protein yields) meet these criteria. Arithmetic averages of skewed or widely varying data do not adequately reflect herd or group performance. Many reproductive indices and values such as SCCs are not distributed normally, and erroneous conclusions about herd performance may be made if averages alone are used to make management decisions. Appropriate frequency distributions are often much more useful for these type of data.

Performance targets should be reviewed at appropriate intervals with realistic expectations regarding the amount of time it takes to effect change in an index. For example, management actions taken to reduce days to first calving would require at least 9 to 10 months to become apparent. A more timely value such as age at conception would more rapidly reflect current management changes. Performance targets should also be amended periodically as industry conditions warrant.

Performance targets can be used to help generate individual herd goals. Goals should not be imposed by the veterinarian but should be agreed on mutually by farm decision makers. Frequent communication and reassessment of goals is an important component of successful health management and production programs.

Minimal Informational Needs

It is extremely important that a system of unique individual cow identification exists. Without this prerequisite it is impossible for a health management program to succeed. Permanent methods of identification include tattoos, color sketches, and hot and freeze branding. The most common methods of animal identification are ear tags, collars, and branding (hot or cold). Increasingly, farms are using electronic identification through the use of transponders on ankle bands or neck straps. The most common use of transponders is identification of cows in the milking parlor to record daily milk weights. Permanent, unique implantable transponders are available and will likely be adopted eventually throughout the industry. At a very minimum, data must be recorded on birth dates, breeding dates, calving dates, and periodic milk yield data. Under ideal circumstances, summarized data should be available for the nutritional program, disease occurrence, and financial performance.

Record analysis is a necessary component of the health management cycle (Fig. 6-8). A health management program without the inclusion of a system to track the success and failure of management decisions is doomed to failure. Most or all DHI systems now allow for the electronic access to performance data, and a variety of computerized systems for individual herd management are used throughout the industry. In many instances, dairy producers and veterinarians are not effectively using existing information sources. The development of information-guided decision-making habits is one hallmark of successful health management programs.

Characteristics of Participants in Successful Health Management Programs

Although health and production management programs are probably beneficial for all dairy farms, not all dairy producers or veterinarians are well suited for participation in them. The commitment to a successful health management program is somewhat analogous to the adoption of a strategic plan. In a survey of strategic planning by family businesses, four reasons were identified for why most family businesses were lacking one (Klinefelter, 2000):

1. **Requires sharing information.** In many instances the commitment to a health management program requires not

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only the sharing of information but also creating of a forum that allows for the generation and discussion of appropriate herd information. In many instances the adoption of a health management program will require time dedicated to analysis and discussion of herd management data. For some herds, recognizing the value of paying for consultative time rather than specific tasks (such as fertility exams or individual animal services) is difficult. The investment in a herd management program is a longer term and less obvious investment compared with the immediate returning of learning whether or not a cow is pregnant. For some farmers it is also difficult to share sensitive information about the financial performance of their business, and in other instances farms are lacking necessary data. A good relationship consisting of trust and mutual respect between the herd veterinarian and the farm owner is a necessity for a successful health and production management program.

2. **Requires the senior management to respond to the ideas of others and defend their own ideas.** Ideally, the producer participating in a health management program has clear, long-term goals for their farm that include constantly looking for new ways to improve the efficiency of production while maintaining product quality and animal health. The producer must believe that attaining herd performance goals will increase the profitability of their business. Producers must also believe that their veterinarians have the expertise to be a credible source of information. Excellent herd managers often read about or observe new management practices of their peers and should be willing to discuss their ideas with their veterinarian. Likewise, many dairy producers are extremely innovative, and the herd veterinarian should be willing to listen and effectively respond to their suggestions. One important communication skill of successful dairy veterinarians is the identification of the "teachable moment"—the time when a farm is most receptive to introduction of a new management idea. An example of a "teachable moment" would be deciding when to initiate discussion of a new milker-training program. Producers are likely to be more receptive to such a program if they believe that their herd will show immediate benefit from it. A herd that is experiencing mastitis or increased bulk tank SCC (BTSCC) will probably be more receptive to such a program compared with one that is currently satisfied with their milk quality.

3. **Increases the opportunity for conflict as a result of differences of opinion.** Most dairy farms are family businesses that have evolved based on decisions of a single individual or family partnerships (husband-wife, father-son, or siblings). As farm owners take on new roles related to management, their traditional role of providing labor (such as milking or feeding cows) are often delegated to others. In some instances no clear mechanism exists for feedback from farm staff regarding the impact of health management programs on their daily jobs. The introduction of practices that have to be implemented by farm staff who may not understand or appreciate the reasons behind the action can be frustrating and self-defeating. In these instances, both active (verbal disagreement) and passive (failure to implement a task or quitting a job) conflict may arise. The same scenario can occur when farm owners disagree with the recommendations of the herd veterinarian but do not have a mechanism to disagree. In these instances the veterinarian may believe that the owner has agreed to implement a program, but progress is impeded because of unresolved issues related to unstated differences of opinion.

4. **Requires a commitment to the plan versus the typical entrepreneurial style of keeping options open.** The successful implementation of a health management and production program requires commitment, such as dedication of time, labor, and capital toward implementation of the program. Farmers who say they are committed to a program but do not designate people to specific tasks or spend money on execution of the program are clearly not convinced of its value.

Producer attitudes and long-term goals are extremely important for the success of a health and production management program. It is obviously more difficult to motivate producers who are planning to exit the dairy industry compared with producers with long-term plans to remain within the industry. In fact, the development of a sound exit strategy should be included in health management programs of terminal dairy farms. There are also some conditions that may delay the introduction and implementation of health management programs. It is important to remember that most dairy businesses are based on family management, therefore many personal issues can influence the performance of the dairy farm. Personal issues such as substance abuse, family disagreements (such as divorce or intergenerational issues), or family tragedies (such as accidents or death) are sporadic distractions from management of the dairy for some producers. The veterinarian is usually a member of the local community and therefore should use awareness of such issues when promoting the adoption of health management programs.

In some instances the farmers are fully convinced about the need for a health management program, but other influences may temper their enthusiasm. Sometimes the client simply does not understand the relationship between suggested interventions and the potential outcome. For example, a farmer may not intuitively understand the link between dry cow housing conditions and clinical mastitis in early lactation. In this instance effective education and a mechanism to demonstrate causality are vital to the success of the program. Many farmers are highly kinesthetic and learn best with a hands-on approach. Visits of neighboring and demonstration farms may help these farmers better understand the need to adopt a practice. Other farmers may rely on the experiences of local key influencers to guide their opinions. In this instance a forum for exchanging ideas between farmers must be available. On some farms, financial limitations make it difficult for farmers to justify what they (or their bankers) may view as unnecessary investments. A carefully justified partial budget may help convince the farmer or the financial partner of the need for a program.

In general, farmers who are successful in implementing health and production management programs are generally numerically literate and business oriented. These farmers are usually willing to listen to advice and make informed decisions based on all available evidence.

Enthusiasm and Competence of Dairy Veterinary Practitioners

The skills and enthusiasm of the veterinary practitioner are an integral component of the health management program. Veterinarians who are successful in offering health and production management programs have to believe they have something to offer the farmer, have the time and ability to offer it, can make a convincing case of its value, and are able to know when to modify practices. Production-oriented dairy practitioners needs to be able to expand the focus of the knowledge and skills that they have already acquired and be able to generate enthusiasm and commitment from their clients for intervention in areas that their clients may not recognize as problems. Health and production management programs are most successful when the skills and motivation of the veterinary practitioner are equally matched by those of the producer (Fig. 6-10). When the skills and

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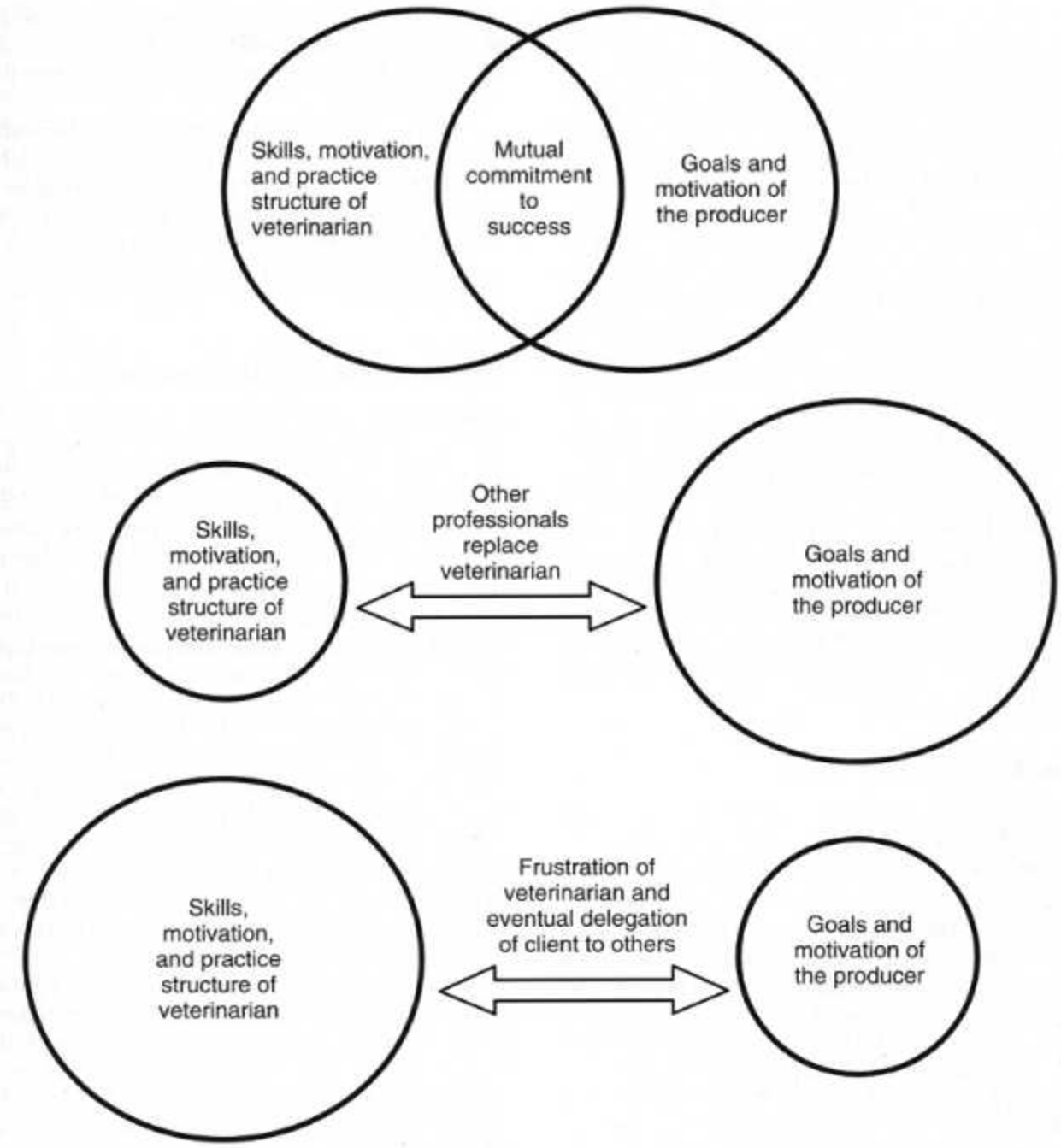

FIG. 6-10 Influence of veterinarian and producer skills and motivation on success of health and production management programs.

motivation of the veterinarian exceed the goals and resources of the producer, the veterinarian will likely feel frustrated and reduce their commitment to the client, sometimes eventually delegating the client to other veterinarians or agri-service professionals. On some farms the producer goals exceed the capabilities (either knowledge or time) of the veterinarian with whom they work. In this instance the producer will likely identify other professionals to supply the desired services.

Clients expect dairy veterinarians to be extremely competent in traditional skills involving diagnosis and treatment of individual animal disease. They also expect the veterinarian to be highly skilled at reproductive examinations and to be able to perform many routine technical tasks such as obstetrical procedures. Veterinarians who offer health and production management programs must also acquire a range of knowledge that extends beyond traditional veterinary skills. Knowledge of the principles of dairy cattle nutrition, milk quality and milking systems, reproductive management, and housing systems—and an understanding of the dairy industry itself—are essential. The dairy veterinarian needs to understand how to acquire and analyze appropriate data and how to communicate its value. The veterinarian must also have an appropriate mechanism for charging clients for time spent on analysis and consulting rather than procedures or services. Another important attribute of veterinarians who offer successful production and health management programs is an ability to communicate with other agri-service providers. This attribute is especially important as farms enlarge and acquire more specialized consultants. Gaining the mutual respect of other agricultural professionals is an excellent mechanism for building a reputation within the dairy community.

SYSTEMS FOR MONITORING HEALTH AND PERFORMANCE

The basis of a health and production management program is the use of a record-keeping system that allows for easy acquisition and analysis of data. Data that are not measured, recorded, and accessible cannot be used in management of the herd. In most instances the record system must be able to chronologically record individual animal events such as calving history, disease events, treatments, reproductive events and examinations, and animal characteristics such as BCS and SCC. The details of record systems are described in Chapter 7. The choice of a record-keeping system tends to vary by farm size, the level of producer education and

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computer literacy, and the availability of a critical mass of users and support staff within a given region. Most monitoring systems can be characterized broadly as one the following: (1) manual (handwritten) card systems, (2) on-farm computer programs, (3) DHI, or (4) DHI and on-farm computer. Regardless of the type of system used by a farm, the monitoring system should meet certain criteria. A comparison of the relative strengths of the various types of systems is presented in Table 6-8. Ease and timeliness of data entry are important so that the monitoring system remains relevant to the day-to-day operations of the dairy. One important function of record systems is the generation of action lists (due to calve, due to dry, etc.). This function is critical in large herds in which cattle are not individually known by the animal handlers and can be overlooked easily. Most systems also provide for a minimal level of herd analysis, such as the generation of timely performance reports for production, reproduction, and disease. Some programs can also generate statistics, such as medians, standard deviations, regression analysis, and process control charts, which are useful for herds that desire advanced analytic capabilities. It is important for the record-keeping system to be flexible and allow the producer and veterinarian to understand and modify the formulas that are used to generate herd performance indices.

Handwritten Card Systems

Handwritten record systems that use individual cow cards for each animal are the most common record system for many small farms. In these systems, each cow has her own card on which events such as calving, breeding, disease, reproductive examinations, and other items are entered. This basic system has been sufficient for many small herds for a number of years because of the relatively small amount of data to be recorded, summarized, and reported. Data entry using these systems is simple, especially for events related to reproductive examinations or treatments, because the producer usually simply carries the card to the cows and records the information as it is generated. The generation of action lists requires a manual examination of each cow card and is generally performed by the producer before herd visits. It is difficult for veterinarians to access data and to generate reports or assess problem areas because there is usually only one copy of the data and the producer needs to maintain the data on the farm. The generation of herd-level indices for benchmarking is also difficult because of the amount of time required to assess each cow card physically.

A lack of farmer motivation and difficulty in demonstrating financial benefits of the program has been identified as one reason that farms do not participate in structured health management programs (Wassell and Chamberlain, 1994). The inability to summarize herd records easily on farms with manual record systems probably contributes to this problem.

On-Farm Computer Systems

Computers were originally used on farms in bureau-type systems designed to provide the veterinary practitioner with a database from which to generate selected indices and herd summary data. Bureau systems required farmers to record data on paper record sheets that were picked up by the veterinarian or a technician. The data were entered into centrally located mainframe computers. Much like the DHI systems of the time, these programs were developed to allow the veterinarian to generate paper reports that could be discussed with the producer each month. Some systems, such as DAISY (Stephens et al, 1979) and FAHRMX (Bartlett et al, 1986) were used to build databases for epidemiological research about disease. Although a tremendous amount of information about disease and performance was learned from these systems, the lack of timely turnaround has limited the widespread implementation of these programs. Bureau and on-farm systems were compared on Ontario dairy farms (Menzies et al, 1988). Farmers invested more time and generated more information with computers located on farms than with bureau-based systems.

The next generation of herd management software was developed to be used on microcomputers located at the farm. Programs such as VAMPP (Noordhuizen et al, 1986), DairyCOMP 305 (Goodger, 1987), and DairyCHAMP (Udomprasert and Williamson, 1990) continue to be developed and used on many farms throughout the world. Veterinarians and consultants also use numerous spreadsheet and goal-setting programs.

In 1996 computers (on-farm or bureau systems) were used to manage about 50% of U.S. cows (NAHMS, 1996). A variety of systems are available, including systems for indi-

TABLE 6-8

Relative Characteristics of Monitoring Systems for Health Management Programs

	Manual Card System	On-Farm Computer	DHI without Computer	On-Farm Computer and DHI
Ease and timeliness of data entry	++	+	+/−	++
Generation of action lists	−	++	+/−	++
Basic analysis of performance	−	+	+	++
Advanced analysis and benchmarking	−	+/−	+	++
Ease of access to data for consultants	−	+	++	++
Handling of disease data	+	++	+/−	++
Flexible and transparent reports	−	+/−	+/−	++
Incorporation of production data	−	+	++	++

DHI, Dairy herd improvement; +, generally available; ++, usually easy; −, can be difficult to accomplish; +/−, varies by system.

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vidual cow management (i.e., dairy herd management software), herd or group management (parlor management software or nutritional software), financial accounting systems and communication packages for Internet access. Individual cow management programs are generally organized like handwritten records with computerized cow cards available to record events and items for each animal. Computerized record systems have advantages over handwritten records in virtually every facet with the exception of data entry. Farms that use computers have been demonstrated to produce more milk compared with herds not using computers (Losinger and Heinrichs, 1996).

Differences exist among the software packages that are currently marketed, and the farm owner should select a program that meets his or her management needs, level of computer literacy, and projected future requirements. The herd veterinarian is often faced with using computer programs on different farms. The practitioner must understand the formulas used in the various programs and assist the producer in proactively defining appropriate indices to monitor herd performance.

Dairy Herd Improvement Association Recording Systems

DHIs began as milk-recording systems set up to provide for comparisons of performance among offspring of service sires used in AI programs. For over 50 years these programs have contributed greatly to genetic progress and productivity in developed dairy regions such as Canada and the United States. The generation of bull proofs remains an important function of these organizations, but they have evolved to be the major provider of management information for about 60% of all dairy farms in the United States and Canada. Another function of DHI systems is to provide data for research and extension programs to foster improvements in the efficiency of production.

DHI systems are based on accurate cow identification, periodic (usually monthly) measures of individual cow yield and components, and recording of appropriate events and items. The data are collected on the farm by a DHI technician or sent electronically to a centralized database, and the amount of information sent to DHI varies by farm. The farmer receives reports with herd summary information. On most farms, milk weights and individual cow data (such as calving and breeding dates) are entered directly into notebook computers and a report is generated before the technician leaves the farm. More extensive reports incorporating component and SCC data are sent after the milk samples have been processed at a central laboratory.

Assuming that data have been recorded and entered accurately, the data submitted to DHI can be used to generate numerous herd reports. Farmers receive a variety of reports depending on their interests and the DHI system to which they belong. Summary reports, action lists, and individual cow data are available. Typical data on a standard herd summary report may include the following:

1. Daily average milk, fat, and protein yields
2. Standardized herd performance measures, such as management level milk or 150-day milk
3. Fat and protein percent
4. Production, income, and feed cost summary
5. Yearly rolling herd averages (RHAs) (milk, fat, and protein)
6. Summarized test day averages for past 12 months
7. Times milked
8. Days in milk
9. Length of lactation
10. Average number of days dry

Reproductive summary data generally include these estimates :

1. Days open to first service
2. Distribution or mean number of days to conception (usually by parity and stage of lactation)
3. Conception rate or services per pregnancy
4. Calving interval and/or projected calving interval
5. Heat detection indices

Herd summary data are usually also available for subclinical mastitis (based on SCC data), heifer management, and genetic progress. Individual cow reports are also available.

Most DHI processing centers have developed programs that allow for the electronic exchange of data and the generation of customized reports. Both commercial and proprietary herd management software can be used to interact with most DHI processing centers. Producers that wish to use the DHI herd management software can enter data directly into their farm computers, transmit the data online to a centralized database, and design and receive customized action lists and reports. In many systems it is also possible to compare herd performance with anonymous peer herds. Web-based systems are also available. These systems have greatly improved the timeliness and usefulness of DHI data. Veterinarians and consultants can access the data and generate reports before herd visits. The ease of data access and report generation allows the development of easily sustainable health- and performance-monitoring programs. The combination of a farm-based computer for daily data entry and the centralized DHI database for herd comparison can be a powerful tool for the dairy practitioner interested in optimizing health and performance of dairy herds.

Use of Computers in Health and Production Management Programs

Computers are an integral component of the health management feedback cycle, and the use of computers enhances the ease and sustainability of most health and production management programs. Veterinarians have a role in assuring accurate data acquisition, focused and useful herd analysis, and knowledge-based management action. The acquisition of data without analysis or action is a waste of resources and is usually unsustainable. The dairy veterinarian who wishes to have an impact on herd performance recognizes that the key to motivating accurate data collection is the use of the data to stimulate action and improve herd performance. One role of the veterinarian is to ensure that collected data are used in a timely manner. The veterinarian not only uses data but also generates data. Therefore the veterinarian can set a good example by recording or entering diagnosis and treatment data into the appropriate record system whenever possible. Accurate data collection is most likely when the producer is using the data frequently and understands its value. The veterinarian should not generate excessive data for which they do not have a system of summarization and reporting. Although many aspects of data acquisition are still based on manual recording systems, automated data collection systems are increasingly used. Automated data collection systems are currently used for collecting individual cow data on milk yield (periodic or daily), conductivity (for mastitis detection), and cow activity (pedometer data used for heat detection). Mottram (1997) projects that automated systems will be used in the future to monitor health and metabolic status of dairy cows. On some larger herds automated collection systems are used to summarize group or herd data, such as parlor performance (milking unit attachment time, milk flow rates, etc.) and feed delivery. It is important for the dairy

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veterinarian to be involved actively with the purpose and function of data collection systems. The veterinarian should review and critically assess the validity of data generated from both manual and automated data collection systems. Knowledge of the accuracy of data collection is useful, and veterinarians should feel comfortable challenging unusual results. For example, when deviations from daily milk yield are used to identify cows for examination, the accuracy of cow identification by the automated identification systems should be known. Unless the farmer is convinced that the data have been collected accurately, analysis based on the results will always be suspect.

Data analysis is the basis of dairy health and performance management programs, but the veterinarian should be judicious in presentation of reports to the dairy producer. The herd evaluation system should be designed to reflect the shared performance goals of the dairy and to detect deviations from performance targets. Computer-generated data are often used for analysis of performance areas. Ideally, the following cycle occurs:

1. The farmer and veterinarian set performance targets based on industry goals, the herd situation, and the resources of the dairy. In most herds, performance targets should be defined for milk yield, reproductive performance, milk quality, replacement management, cow removal, and animal health. Additional specific performance targets such as financial performance may be included on some herds.

2. A system of assessing key indicators for the performance targets should be defined. The monitoring system should specify the indices used, the animals included, and the time interval for reassessing progress made toward reaching each target. When data is available, it is probably useful to review some data (such as daily milk weights or dry matter intakes) more frequently than once a month, depending on the schedule of routine herd visits. Time should be dedicated specifically to review of data. Veterinarians who have remote access to data may wish to generate and review reports before visiting the herd, but it is important that both the producer and veterinarian have similar expectations regarding the importance of herd performance monitoring. Specific details on each area of performance are described within the appropriate chapter of this book, but a summary of some typical performance indicators routinely generated by computers is included here:

a. Milk production. Milk yield per cow per day on either a daily or monthly basis is usually used as the primary indicator of herd productivity. Most computer programs further define milk yield by parity and stage of lactation, and most can generate individual cow and group lactation curves. Lactation curves are useful to visual performance, but they should not be overinterpreted. Differences in the number of animals contributing to points of the lactation curve and innate variation can contribute to erroneous interpretation of the results. Peak milk yield occurs for most cows at 40 to 70 days after calving. Assessing peak milk yield allows assessment of dry cow and fresh cow management. A prediction of total lactation yield can be made by multiplying peak yield (in lb) by 220. For example a cow producing 100 lb of milk at peak would be expected to produce 22,000 lb throughout her lactation. Milk yield data are most useful when they are current and reflect specific management changes. Milk per cow per day responds rapidly to on-farm conditions such as feed changes or environmental extremes. It is generally useful to also monitor long-term trends in milk yield through the use of RHAs. RHAs carry tremendous momentum and should not be relied on to assess current conditions, but they can indicate past performance and long-term trends. Adjusted milk yields such as adjusted corrected milk, 150-day milk, or management level milk are also useful to remove biases introduced by changes in herd composition or stage of lactation. Milk components should also be monitored, since they are an important part of overall productivity and can reflect dietary changes.

b. Reproductive performance. In general, key current indicators of fertility include the calving-to-conception interval, the interval from calving to first service, conception rate, pregnancy rate (defined as the conception rate times the percent of eligible animals bred within a defined time period), heat detection, and reproductive cull rate. These values are often assessed by parity. While averages have been the traditional method of assessing these values, the use of flexible computer programs has increased the number of consultants who are reviewing and setting goals based on the distribution of values. The most effective herd monitor is one that rapidly reflects a breakdown in the system. The need to wait for 21 to 35 days after breeding for expression of estrus or confirmation of pregnancy creates a lag period between action and analysis for most reproductive statistics. Some reproductive statistics, such as days to first service calculated for animals receiving a first service in a defined time interval, are rapid reflections of herd status. Veterinarians who introduce programmed breeding systems relying on injections of gonadotropin-releasing hormone and prostaglandin (described in Chapter 7) should critically evaluate the success of these programs on a regular basis through the use of appropriate monitors such as pregnancy rate.

c. Milk quality. The BTSCC is a key indicator of milk quality and should be reported frequently to ensure that subclinical mastitis outbreaks are detected in a timely fashion. The dairy practitioner should recognize that BTSCC does not reflect the incidence or prevalence of intramammary infection within the herd; therefore a summary of individual cow SCC values by stage of lactation and parity is necessary. It is well known that individual cow SCC values are not distributed normally, so the use of linear scores should be encouraged. Computer reports that indicate the new rate of subclinical infections are useful for detection of developing problems. Many reports include a summary of the rate of clinical mastitis. The veterinarian should be cautious in using this data without validating its accuracy, since many farms do not record all detected mastitis.

d. Replacement management. Diarrhea and respiratory disease are the most significant diseases of calves and should be monitored continually. A consistent mechanism for entry of disease and death events is often lacking for youngstock. Calves are generally housed in separate facilities or removed to dedicated calf-rearing businesses. The use of remote data entry can be helpful to overcome some of these issues. Age and weight at breeding and conception are useful summary data for monitoring programs but require dedication to the system of data entry. The age at first calving is often included in monitoring programs but is simply a long-overdue reflection of the success or failure of past efforts.

e. Cow removal. The herd veterinarian should frequently assess both the rate and reasons for cow removal. Cows are often culled for multiple reasons, and the on-farm computer may not accurately reflect underlying causes. For example, a cow may be listed as culled for low production, but in reality the low production may be a consequence of an extended calving interval because of infertility. The rate of adult cow mortality should also be monitored, since a high cow mortality rate is the effect of inadequate disease detection systems.

f. Animal health. Rates of the most common preventable diseases of dairy cows (milk fever, DA, ketosis, dystocia, retained placenta, lameness, metritis, and abortion) can be summarized easily with computerized herd programs. The veterinarian should advise the farmer about case definitions and appropriate at-risk populations to include in the statis-

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tics. The definition of the at-risk population used to monitor these diseases is critical to ensure that the statistic sensitively detects changes in the incidence of disease.

g. Special reports. The veterinarian may generate a more detailed report specific to an identified problem. For example, a summary report looking for risk factors for clinical mastitis or DAs may be appropriate to generate if herd indices indicated unacceptable performance in these areas. Additional reports summarizing breeding performance or annual trends may be generated periodically.

3. The producer and the veterinarian agree on defined actions. Actions should be justified based on the herd status and goals. Actions are generally diagnostic, preventive, or treatment oriented. Computers are often used to generate the action lists. Typical activities could include: generation of lists of animals for routine herd fertility exams, examination for illness, selection of cows to obtain milk samples for culture, animals to vaccinate, animals to consider culling, animals to breed, animals to receive BCS, or animals requiring treatments. At this point the cycle repeats when the results of the actions are entered into the computer program.

COMPONENTS OF A DAIRY HEALTH AND PRODUCTION MANAGEMENT PROGRAM

There is considerable variation in the structure of dairy health and production management programs. Numerous dairy practices offer comprehensive health and production management programs that are successful and sustainable. Other practices struggle to define and provide programs that extend beyond routine technical services offered on a monthly basis. In most instances modern health and production management programs have slowly evolved from "herd-health" programs that were focused on rectal palpation. Many informal discussions about diverse management issues occurred over the backs of cows during these early programs, but these programs generally lacked explicit goals and veterinary compensation because management advice was often captured indirectly through the sale of pharmaceutical products. While some programs are still offered in this fashion today, the most successful health management programs offer comprehensive services across a spectrum of dairy herd management (Fig. 6-6).

Regularly Scheduled Farm Visits

The basic structure of the health management program includes scheduled herd visits by the dairy veterinarian. The frequency of scheduled visits is variable and somewhat dependent on herd size. In herds of less than 100 cows, one or two cows calve every week and a single scheduled monthly visit is probably appropriate. These herds may have more unscheduled visits for examination of sick cows compared with herds that are visited more regularly. Larger herds that are calving cows on a daily basis warrant more frequent visits, and weekly scheduled visits are not uncommon for herds of more than 200 cows. A developing trend on extremely large dairy farms (more than 2000 cows) is the employment of a staff veterinarian to oversee and direct day-to-day issues regarding health and performance. The frequency of scheduled herd visits for grass-based seasonal dairy operations varies depending on the stage of lactation of the herd. More frequent visits are necessary in early lactation and during the breeding period of these herds.

Activities at Scheduled Visits

Activities at herd visits fall into four general categories (Fig. 6-6). The foundation of successful health management programs is excellence in provision of *individual animal health care and emergency services.* The remaining activities are grouped as *scheduled technical activities, scheduled analytic and training activities* and the provision of *quality control programs.* The frequency of individual activities will vary, but a schedule defining the minimum suggested frequency is shown in Table 6-9.

TABLE 6-9

*Suggested Frequency of Scheduled Herd Activities for Health and Production Management Programs**

Frequency of Activity	Activity
Weekly or biweekly	Individual animal care and treatment
	Fertility examinations
	Body condition scoring
	Collect diagnostic samples (California Mastitis Test results; milk samples, calf serum, etc.)
Monthly	Dry matter intake
	Feed bunk scoring
	Pasture walks
	Total mixed ration analysis
	Targeted performance reviews
Quarterly	Protocol development and review
	Training sessions
	Consultation with other farm advisors
Semiannually	Parlor observations
	Teat scoring
	Review of financial analysis
Annually	Strategic planning and goal setting
	Milking systems analysis during milking (should be much more frequent for larger dairy farms)

*This schedule is representative of a schedule for a middle- to large-sized dairy and should be amended for individual farm conditions.

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Individual Health Care and Emergency Services

The provision of traditional veterinary skills involving examination and treatment of animals is an important activity during scheduled visits to the dairy. A frequent schedule of herd visits allows the practitioner to examine cows early in the course of disease when the likelihood of successful treatment is higher. Routine visits also allow the veterinarian to monitor the outcome of treatments and modify treatment protocols as needed. Ideally, the monitoring program includes a system to detect cows that are not performing as expected. Special emphasis should be directed toward the highest-risk cows, including frequent observation of animals during the periparturient period. On small dairy farms, the farm owner is often familiar with individual cows and observes behavioral changes, such as reduced milk yield, anorexia, or lethargy. As farm size increases, it becomes less likely that individual cow behavioral changes will be noticed. In these herds computer-generated lists may be used to select cows for examination. The computer may flag cows that reduce activity (when pedometers are used) or exhibit large drops in daily milk yield. On many large dairy farms an animal handler is assigned to work directly with the group of animals that have recently calved. Some farms have adopted a system that includes routine daily monitoring of body temperature and rumen activity of cows during the first 7 days after calving. Animals that fall outside of normal limits are treated according to predefined criteria or detained for examination by the herd veterinarian. All treatments administered to dairy cows should be recorded in treatment logs (either computerized or handwritten) to assure adherence to proper meat and milk withholding periods.

The frequency of unscheduled visits for emergency medical services usually diminishes on herds that have adopted a health and production management program. In many instances the herd veterinarian trains the producer or animal handler to administer a standard treatment for common diseases. On large dairy farms many animal handlers become proficient in routine activities such as intravenous treatments or simple obstetrical procedures. On these farms the veterinarian should develop a system for staff training and evaluation.

Scheduled, Traditional, Technical Activities

Routine reproductive examinations continue to consume a considerable amount of the veterinarian's time during scheduled herd visits. Attaining reproductive success is an essential determinant of herd productivity. Reproductive programs are fully described in Chapter 7, but it is useful to be reminded that the end point of fertility examinations should be to generate data that can be used to determine the success or failure of breeding programs. The implementation, success, and cost-effectiveness of scheduled breeding programs should be reviewed frequently. It is also common to monitor the effect of the nutritional program by recording BCSs for selected animals. BCSs drop rapidly after calving, reach a nadir by 50 to 80 days after calving, and gradually increase throughout the rest of the lactation (Ruegg and Milton, 1995). BCSs are a good indicator of how the delivered diet meets the energy needs of the cows. While the process of body condition scoring focuses attention on the nutritional adequacy of the diet, a mechanism of summarizing BCS for groups of animals is necessary for full use of the data.

On smaller farms, it is often customary for the veterinarian to perform routine individual animal treatments (such as intravenous injections), prophylactic activities (such as vaccinations) and some technical tasks (such as dehorning calves) during scheduled herd visits. It is appropriate for the veterinarian to perform these tasks because the farm staff may not do the tasks often enough to become technically proficient. On many larger farms these tasks may be performed on a daily basis and animal handlers may become quite competent.

Quality Control Programs

Programs that involve activities directed toward "quality control" are an additional subset of scheduled technical activities. "Quality control" refers to activities that ensure consistency in carrying out key management processes. Vital management areas for most herds include nutritional management, milking management, and youngstock programs. Some farms may also develop quality control processes for environment and housing and farm-specific management of breeding bulls.

Nutritional Management

Advising farms about nutrition is a key activity for dairy cattle practitioners. Feed costs constitute approximately 60% of the total cost of producing milk, and even minor improvements in feeding efficiency can be profitable (Ferguson et al, 1987). Some dairy practitioners function as the nutritional specialists for the dairy farms they serve. They may collect feed samples for nutrient analysis, formulate rations, and advise the farmer regarding crop and harvesting conditions. These veterinarians often devote a considerable amount of their professional time to nutritional management. Chapter 11 describes nutritional management in great detail.

It is common for farms to employ a professional nutritionist or to use a nutritionist employed by a feed company or local cooperative. These professional nutritionists generally formulate the rations and submit feed samples for nutrient analysis. On these herds the veterinarian can have an important role in ensuring that the diet described on paper is adequately formulated and delivered to the cows. Routine scheduled activities such as measuring the dry matter of forages, hand mixing a TMR for one cow and comparing it with the machine-mixed TMR ("TMR test mix"), and scoring the feed bunk to assess feed sorting and dry matter intake are important procedures that help to ensure the successful delivery of a nutritional program. Assessing pasture conditions by periodic inspection of pasture is an important component of managing the nutritional program of herds that use management-intensive grazing. These quality control activities should be conducted routinely as part of the health and production management program.

Milking Management

Achievement of a consistent milking routine is the key to quality milk and is a goal of most farmers. However, many farms have not explicitly described the milking process for their personnel. Less than 20% of Wisconsin farms participating in milk quality teams had written milking routines before beginning the project (Ruegg, 2000). There is tremendous variability in milking routine reported by farmers. In a nonrandom survey of 338 Wisconsin dairy producers, four milking routines accounted for 63% of all routines used but the remaining 117 herds reported using an additional 23 milking routines. In some instances milking staff on the same farm use different milking processes. Milking management should be a standard element of quality control programs. Tasks such as observation of the

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milking routine and scoring the condition of teats should be performed at least quarterly. The milking system should be analyzed during milking on a scheduled basis depending on milking frequency and herd size. All herds should have key indicators of have their milking system assessed at least annually.

Mastitis control programs are most successful when the practitioner knows the type of mastitis pathogens that are prevalent on the dairy. A scheduled system of routine screening for mastitis pathogens can be implemented as part of the milking management program. The veterinarian can teach farm personnel how to perform the California Mastitis Test (CMT) as part of a surveillance program. Animals routinely screened may include cows at dry off, fresh cows and heifers, and newly purchased cows. Milk samples can be collected and submitted for culture from quarters that show positive reactions to the CMT.

Youngstock Management

Newborn calves and replacement heifers are often housed separately from the lactating cows and may not be observed routinely by the herd veterinarian. In some cases, the veterinarian only interacts with youngstock when a health crisis develops. As described in Chapter 9, the management and delivery of colostrum is a critical control point for calf health. It is relatively simple to implement a routine surveillance system that assesses the adequacy of colostral absorption. As part of scheduled herd visits the veterinarian can collect and test blood samples from selected calves for either immunoglobulin or serum protein levels. On small herds it may be cost effective to routinely test all calves less than 10 days of age at the visit, whereas larger herds may elect to test a random sample of younger calves.

The most visible manifestation of replacement management is the growth rate. Growth rates reflect both nutritional management and the adequacy of disease control and should be monitored to ensure that animals reach the appropriate weight for breeding by 13 to 15 months of age. Measuring the height and weight of heifers is a labor-intensive task that can be delegated to farm personnel on large dairy farms, but the herd veterinarian should review the data routinely. On small farms the veterinarian may measure animals when they are restrained for immunizations or other prophylactic activities.

Environmental Management

Dairy cattle housing is presented in Chapter 12. The environment of dairy cattle can have considerable influence on health and productivity. Some veterinarians recognize this issue and routinely schedule "walk-abouts" through the housing areas to assess factors related to animal comfort and hygiene. Udder cleanliness, hoof and hock lesions, and respiratory disease are often determined by housing conditions. Herd walk-abouts should include areas that are often ignored, such as dry cow and heifer housing.

Breeding Bull Management

Although most dairy farms use AI, many also use bulls to breed animals that have not conceived through the use of routine AI programs. Some farms use bulls to breed the majority of their herd. In many instances these bulls have not been screened for fertility even by simple tests such as scrotal circumference. The management of breeding bulls in dairy herds that use them should be a part of the routine technical activities of the veterinarian. The dairy practitioner should offer breeding soundness examinations, routinely observe the bulls for lameness, and discuss management issues such as the ratio of open cows to breeding bulls, bull rotation, and rest schedules.

Scheduled Analytic and Training Activities

The delivery of scheduled or unscheduled technical activities will not be effective unless there is a system that captures the results of the activities and allows for analysis and ongoing revision. The structure of the health and production management program must include time for the farmer and the herd veterinarian to analyze and discuss herd management issues. In herds that are dependent on hired personnel to implement designated tasks, time must be scheduled to effectively train the personnel that are ultimately responsible for delivery of the programs. There are at least four broad areas that can be included in herd visits: performance reviews, protocol development and review, training activities, and consultation with other farm advisors.

Performance Reviews

It is useful for the herd manager and veterinarian to review herd performance on a regular basis. Performance reviews should be respected as a part of the health and production management program and should not be performed after a tiring session of reproductive exams or surgical procedures have been completed. Time for performance reviews should be realistically allocated, and the farm staff should gather the data needed for the discussion beforehand. The discussion should be based on a comparison of selected herd performance indicators against the herd performance targets. Each discussion should end with the generation of an action list that states who is responsible for implementation. A time period and method of evaluation should also be stated for each action item. Actions and relevant decisions should be documented to aid in communication and future discussions. It is important to realistically assess the farm capabilities. Performance reviews should be a positive experience that allows the producer to define and reach herd goals. When performance is lacking in a number of areas (such as reproductive performance or milk yield), prioritizing activities based on the expected return is useful (Fig. 6-11). Interventions should be targeted toward the areas that are feasible and will show the highest return to the farm. A comprehensive session of strategic planning should be scheduled at least annually. This session should review the performance of the past year and set performance goals for the upcoming year.

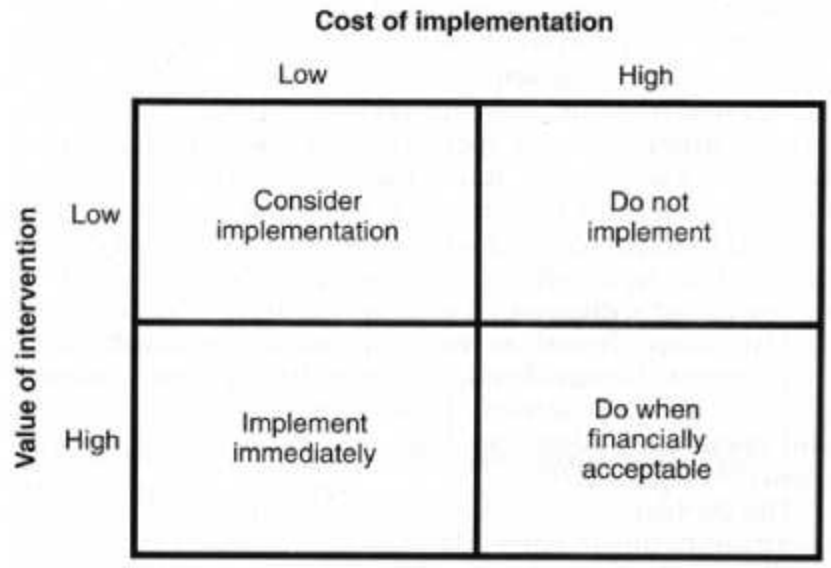

FIG. 6-11 Prioritization of health management decisions.

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As part of the health management program, some veterinarians become involved in financial management of the dairy operation. The veterinarian often becomes interested in financial management when he or she wants to evaluate the expected financial impact of proposed changes in management. The initial step in economic assessment should be to define the producers' goals and objectives (Hady and Lloyd, 1993). Partial budgeting is a tool that can be applied to project changes in profitability resulting from proposed management changes (Lloyd and Hady, 1994). A partial budget is a static assessment of the net expected change in profitability based on adoption of a management change. It is simple to construct based on farm data. The first step is to add estimated *increased revenue* resulting from a management change to estimates of *decreased expenses* assignable to the management change. The sum of *decreased revenues* and *increased expenses* expected to occur based on adopting the change is then subtracted, leaving the net expected change in profitability. Partial budgets should be calculated routinely as part of the decision-making process on the dairy.

Some veterinarians move beyond partial budgets to true financial management. Cash flow analysis has been recommended as a tool for veterinarians to use to help producers identify management opportunities, establish capital expenditure priorities, and to project the future viability of the dairy (Ferry, 1994). Cash flow analysis is a listing of all annual expenses compared with income. The development of inexpensive accounting software has simplified these analyses.

Protocol Development and Review

On an increasing number of farms, the production of quality milk and the maintenance of animal well-being depends on continuous effort by non-family employees. The development of SOPs is one method that an increasing number of farms are using to ensure that agreed-on processes are implemented. SOPs are commonly developed to define the optimum milking routine on a farm. A typical SOP describes the premilking cow preparation, unit attachment routine, and method for postmilking teat disinfection. An increasing number of mid- and large-sized dairy farms also define disease surveillance systems for fresh cows. The fresh cow SOP may include daily observation and a brief physical of each cow for the first 5 to 7 days after calving. Farm staff generally carry out these activities. It is well within the skill set of most dairy veterinarians to take an active role in the development of these processes and to help ensure that staff is adequately trained to carry out their assigned roles.

Treatment protocols are used to define standard treatments for common diseases on dairy farms. Treatment protocols are advocated when multiple people have responsibility for administering antibiotic treatments to dairy cattle or when extralabel drug use (ELDU) is prescribed. ELDU is any use of a drug that is not specifically mentioned on the product label, such as the following: administration of intramammary mastitis treatments at 8-hour intervals when the product label prescribes 12-hour intervals; administration of 30 ml of an agent when the dosage listed on the label is 15 ml; or use of a product labeled for the treatment of footrot or respiratory disease to treat any other condition. Treatment protocols provide a mechanism for increased communication about treatment plans between the veterinarian and client and allow the farm to partially fulfill requirements for legal ELDU.

The avoidance of residues in food products is a major responsibility of the dairy practitioner. Increased scrutiny regarding antimicrobial use in food producing animals has arisen because of concern about the development of antimicrobial resistance in foodborne pathogens. Veterinarians and producers use antimicrobial agents to treat many infectious diseases of dairy cattle; these agents are justified to protect the well being of the animals. Treatment of mastitis is the most common reason for the use of antibiotics on dairy farms (Allison, 1985). The use of lactating and dry cow intramammary antibiotics and the mistakes regarding withholding periods of milk are the most frequently cited reasons for antibiotic residues (Booth and Harding, 1986; McEwen et al, 1991). Although the level of detected antibiotic residues in meat and milk products is extremely low, antibiotic residues in bulk milk and carcasses occasionally occur. In the United States contamination of bulk milk is rare because of an effective surveillance system based on rapid testing for selected antimicrobial agents of every load of raw milk. Milk that is contaminated with antibiotics is discarded, and the producer is fined.

The requirements for ELDU have been defined by U.S. regulatory officials under the Animal Medicinal Drug Use Clarification Act (or AMDUCA):

- For food animals, ELDU is not permitted if a drug exists that is labeled for the food animal species and contains the needed ingredient, is in the proper dosage form, is labeled for the indication, and is clinically effective.
- ELDU is permitted only by or under the supervision of a veterinarian.
- ELDU is allowed only for FDA-approved animal and human drugs.
- ELDU is permitted for therapeutic purposes only when an animal's health is suffering or threatened. ELDU is not permitted for production drugs (e.g., growth promotion).
- ELDU in feed is prohibited.
- ELDU is permitted for preventive purposes when an animal's health is threatened.
- ELDU is not permitted if it results in a violative food residue, or any residue that may present a risk to public health.
- ELDU requires scientifically based drug withdrawal times to ensure food safety.
- The record and labeling requirements must be met.
- The FDA prohibits specific ELDU. For example, the following drugs are prohibited for extralabel use in food animals: chloramphenicol, clenbuterol, diethylstilbestrol, dimetridazole, ipronidazole, other nitroimidazoles, furazolidone (except for approved topical use), nitrofurazone (except for approved topical use), sulfonamide drugs in lactating dairy cows (except approved use of sulfadimethoxine, sulfabromomethazine, and sufaethoxypyridazine), fluoroquinolones, and glycopeptides (e.g., vancomycin).

The American Association of Bovine Practitioners (AABP) has responded to societal and regulatory concerns about the use of antimicrobial agents by adopting the following recommendations for the prudent and judicious use of antimicrobial agents in dairy cattle (Prudent drug use, 2000):

1. The veterinarian should accept responsibility for helping clients design management, immunization, housing, and nutritional programs that will reduce the incidence of disease and the need for antimicrobials.

2. The use of antimicrobials only within the confines of a valid veterinarian-client-patient relationship (VCPR), for both dispensing and the issuance of prescriptions, has been recommended by the AABP. A valid VCPR exists when all of the following conditions have been met:

   a. The veterinarian has assumed the responsibility for making clinical judgments regarding the health of the animal(s) and the need for medical treatment, and the client has agreed to follow the veterinarian's instructions.

   b. The veterinarian has sufficient knowledge of the animal(s) to initiate at least a general or preliminary diagnosis

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of the medical condition of the animal(s). This means that the veterinarian has recently seen and is personally acquainted with the keeping and care of the animal(s) by virtue of an examination of the animal(s) or by medically appropriate and timely visits to the premises where the animals(s) are kept.

c. The veterinarian is readily available for follow-up evaluation, or has arranged for emergency coverage, in the event of adverse reactions or failure of the treatment regimen.

3. Veterinarians should properly select and use antimicrobial drugs. Veterinarians should participate in continuing education programs that include therapeutics and emergence and/or development of antimicrobial resistance.

4. The veterinarian should have strong clinical evidence of the identity of the pathogen causing the disease, based on clinical signs, history, necropsy examination, laboratory data, and past experience before making a recommendation for antimicrobial use.

5. Antimicrobials should be used at a dosage and duration appropriate for the condition treated.

6. Product choices and regimens should be based on available laboratory and label (including package insert) information, additional data in the literature, and consideration of the pharmacokinetics, spectrum, and pharmacodynamics of the drug.

7. Antimicrobials should be used with specific clinical outcome(s) in mind, such as fever reduction, return of mastitis milk to normal, elimination or reduction of shedding, contagion, and recurrence of disease.

8. Periodically monitor herd pathogen susceptibility and therapeutic response, especially for routine therapy such as dry cow intramammary antibiotics, to detect changes in microbial susceptibility and to evaluate antimicrobial selections.

9. Use products that have the narrowest spectrum of activity and known efficacy in vivo against the pathogen causing the disease problem.

10. Antimicrobials should be used at a dosage appropriate for the condition treated and for as short a period of time as reasonable. Therapy should be discontinued when it is apparent that the immune system can manage the disease, reduce pathogen shedding, and minimize recurrence of clinical disease or development of the carrier state.

11. When possible, antimicrobials of lesser importance in human medicine should be chosen before choosing a newer generation animal antimicrobial that may be in the same class as a human antimicrobial that may be used as the primary or sole treatment for a human infection. An antimicrobial for which emergence of resistance is expected to be in an advanced stage, should also not be chosen.

12. Antimicrobials labeled for use for treating the condition diagnosed should be used whenever possible.

13. Combination antimicrobial therapy should be discouraged unless there is information to show increase in efficacy or suppression of resistance development for the target organism. Compounding of antimicrobial formulations should be avoided.

14. When appropriate, local therapy (e.g., intramammary, intrauterine, topical) is preferred over systemic therapy.

15. Treatment of chronic cases or those with a poor chance of recovery should be avoided.

16. Prophylactic or metaphylactic use of antimicrobials should be based on a group, source, or production unit evaluation; rather than being utilized as standard practice.

17. Veterinarians should endeavor to ensure proper on-farm drug use. Drug integrity should be protected through proper handling, storage, and observation of the expiration date.

18. Prescription or dispensed drug quantities should be appropriate to the production unit size and expected need so that stockpiling of antimicrobials on the farm is avoided.

19. The veterinarian should train farm personnel who use antimicrobials on indications, dosages, withdrawal times, route of administration, injection site precautions, storage, handling, record keeping, and accurate diagnosis of common diseases.

20. Veterinarians are encouraged to provide written, updated protocols for diagnosis and treatment to clients whenever possible. Those protocols should describe conditions and provide instructions for antimicrobial use at a farm or unit when a veterinarian is unavailable.

Health and production management programs are central to the concept of judicious and prudent antimicrobial use on dairy farms. The development of treatment protocols and SOPs are recommended to meet the criteria for establishing effective therapeutic programs.

Training

The development of treatment protocols and SOPs requires strategies to ensure that employees understand the importance of following written procedures. Most small to mid-sized dairy farms have relatively few employees, and implementation is likely if the farm owner agrees with a process. Larger dairies depend on the continuous performance of hired staff that may have limited experience or conflicting opinions about the necessity to follow an SOP. One role of the veterinarian is to ensure that animal handlers and milking staff are adequately trained so that they can carry out agreed-on procedures. Training is a continuous function. There is a need to train new employees and a need to retrain long-term employees when procedures are changed. Training sessions that are prepared and delivered well can help raise the consciousness of the staff regarding the importance of following procedures.

Consultation with Other Advisors

On many farms the veterinarian should reserve time to consult with other advisors regarding farm performance. In many instances the nutritionist can be a vital ally. Critical farm advisors may also include financial consultants, extension agents, technical service veterinarians and dairy plant field staff. In the worst of circumstances, the farmer receives conflicting advice from various sources and elects to do nothing. In the best of circumstances, farm advisors meet and communicate frequently and unite around farm goals.

Investigations of Health and Production Problems

Even on the best managed farms, unexpected health and production problems arise. Surveillance programs incorporated in health and production management programs should detect problems early before considerable financial damage has occurred. Systems of investigating herd outbreaks have been described (Ruegg, 1993). Epidemiological concepts of disease investigation are useful to identify risk factors and to stimulate corrective action. Quantitative skills useful in herd investigation are described in Chapter 2.

Reasons for Failure of Health and Production Medicine Programs

Not all health and production management programs are successful. The maintenance and growth of a dairy health management program requires the continued motivation

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and interest of both the farmer and the veterinarian. It also requires continual communication and a willingness to be flexible and responsive to changes in farm conditions. Some causes of failure of programs include the following:

- Mismatching of producer expectations with veterinary skills and motivation or vice versa (see Fig. 6-10). Programs can fail because of either unrealized producer expectations or unrealized veterinary expectations. In either case it is likely that the unsatisfied party will seek out a better match for their needs.
- Inability of the veterinarian to arrive at the farm at scheduled times for nonemergency services. This may be due to a practice schedule that places more priority on provision of emergency services than on consultative services.
- Inadequate communication between the veterinarian and the producer.
- Overwhelming the farmer with recommendations.
- Poor implementation of recommendations by either the veterinarian or farm staff.
- Failure to analyze results and modify practices. This often creates a vicious cycle of diminished interest in data recording, leading to diminished ability to assess performance.
- Inappropriate fee structure for veterinarian. Unless the veterinarian can be compensated properly for time spent on consultative activities, the priority of consultative activities will always be less than the priority of revenue-generating activities.

IMPLEMENTATION AND FINANCIAL ASPECTS OF DAIRY HEALTH MANAGEMENT PROGRAMS

Many veterinarians recognize the income potential of health and production management programs. In surveys by the American Veterinary Medical Association, greater than two thirds of food animal veterinarians believed that herd health management services represent the area of greatest long-term potential for practice revenue growth (Wise, 1987). In spite of this recognition the complete potential of health and production management programs remains unrealized for many practices (Nordlund, 1998; Wassell, 1995). A paradigm for the development of health and production medicine programs has been proposed for practitioners (Nordlund, 1998):

1. Acquire the appropriate skill set including knowledge of dairy record and monitoring systems, disease management including statistical and epidemiological analysis techniques, and an understanding of dairy finance including cost of production determinations and partial budgeting. Attend continuing education programs to accelerate the learning curve.
2. Let clients know what is being offered by using brochures and business cards that describe those services. Do not market pet grooming and 24-hour-a-day emergency services on the same card.
3. Arrange clinic schedules so that each interested veterinarian gets designated time to develop management assistance services. Identify days or weeks where those veterinarians are excluded from sick cow calls and emergency services.
4. Start herd visits with an overview of herd performance, not by wearing an examination sleeve into the barn. Take a few minutes to review or monitor the herd records and performance, make notes or update a graph, then go back to the vehicle for the sleeve and reproductive examination kit.
5. Work with the herd manager to define herd management goals.
6. Use veterinary technicians in the delivery of dairy services. Many dairy services can be facilitated by a technician, including data recording or entry; sample collection including milk, urine, blood, fecal and feedstuffs; and preparation and assistance with procedures.

A survey of veterinary practitioners in the United Kingdom reported that 78% of veterinarians believed that herd health programs would be financially beneficial to a practice (Wassell, 1995). This survey clearly identified "farmer motivation" as the veterinarians' main perception of why some herd health programs failed. This survey then assessed farm clients to determine if differences exist between farms that use routine veterinary services versus emergency-call-only services. Differences in farm size, herd size, seasonality of calving, education, progressiveness, and level of communication were noted. The successful operation of a health and production management program depends on the following features of the veterinary practice (Esslemont, 1995):

- Commitment: agreement and support among practice members should be sought before initiation of a program
- Self-appraisal: review the level of knowledge and skills of the veterinarians offering the program. Recognize when to refer a problem or seek expert advice when limitations exist
- Market research: identify and target clients who are most likely to succeed and start by offering the program to a limited number of clients
- Farm appraisal: use a method for assessing farm's losses and targeting problem areas
- Selling skills to get the herd started: retrospective data should be collected to generate a history of performance
- Setting up a pricing system
- Practice meetings: newsletter production as well as training and interpretation of reports can help generate enthusiasm among clients
- Financial analysis

Compensation for the Veterinarian

Veterinary compensation derived from health and production medicine programs includes both the intangible benefit of contributing to the success of the dairy and the tangible benefit of enhancing personal income. The decision to offer or expand consultative services means that virtually all practices have to reach a decision on how to charge for professional time. Traditionally, veterinary practices subsidized time spent consulting with fees from other services such as emergency visits or high margins on items (such as pharmaceuticals) that were dispensed. The purchasing power of larger dairy farms and the proliferation of pharmaceutical suppliers has limited income from drug sales. The most common methods of charging producers for professional veterinary services are to charge by procedure, time, or contract (Gardner, 1989). Additional charges are usually assessed for visiting the farm (mileage or a standard fee) and dispensing of animal health supplies. Some practices monitor the marginal return above drug cost to assess the relative profitability of various services.

Some practices continue to bill clients based on procedures performed during the herd visit. This system is quite visible to the client and is generally readily accepted because of the tangible results. Examples include reproductive examinations, foot trimming, collection of milk samples, and examination of individual cow problems. There are two major disadvantages of using this method. The client has no financial incentive to be prepared for the visit or to pro-

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vide for adequate restraint or labor. With this method, adequately charge for time spent on consultation is extremely difficult. The client may not perceive time spent discussing management issues as a billable service. The veterinarian may feel compelled to rapidly complete tasks that generate income and to minimize the time spent developing non-income-generating health management programs. This system has a long history within traditional bounds of the veterinary-client relationship but is generally limited in its applicability to effective health and production management programs.

Most professional service providers charge hourly fees for time spent completing professional tasks. This method of charging is gradually becoming the standard for many dairy practices. Using this system, the veterinarian generally charges a call fee to visit the farm and then adds an hourly fee for time spent on health management work. This system is based on assigning value to professional knowledge and skills delivered over units of time. There may be large discrepancies in hourly fee structures between veterinarians depending on the marketability of their skills and existing local competition. Hourly fees generally range from $45 to about $150. This system is advantageous in that it allows the veterinarian to get paid for actual work done on the farm, which may include diagnostic skills such as palpation, review of records, interpretation of laboratory results, ration analysis, on-farm data entry, and discussions of herd problems with the producer or other consultants. The use of hourly fees to charge for these services is generally readily accepted by the client, but in many instances veterinarians find it somewhat challenging to charge for off-farm services such as record analysis or telephone consultations. Charging by the hour also encourages most producers to attempt to be organized when the veterinarian reaches the farm. This allows for more efficient use of both the veterinarian's and producer's time.

Some practices have defined services that are provided on a scheduled basis and charge a set fee to deliver those services during a specific period (generally an annual basis). These contract services may be based on identification of herd specific goals but most commonly are based on charging a set fee per animal. In most instances contracts for annual health management programs do not include veterinary fees and expenses for emergency veterinary service nor costs of veterinary supplies and drugs. The use of contracts may be advantageous to both the producer and veterinarian in that it allows both parties to project their expenses (or income) in return for specified services. If the amount of work exceeds expectations, this system may be disadvantageous to the practitioner.

Profitability of Health and Production Management Programs

The cost-effectiveness of producer investments in effective health and production medicine programs has been demonstrated repeatedly. It is almost intuitive that programs that reduce losses in productivity because of disease will be beneficial for the dairy producer. Traditional programs that have focused on improvements in reproductive efficiency and milk quality have been known to be effective for over 30 years (Barfoot et al, 1971; Blood et al, 1978; Ellis and James, 1979). One study assessed the long-term performance of herds that were enrolled in herd health management programs for a 2-year period (Hogeveen et al, 1992). This case-control study compared the financial performance of herds enrolled in the program to financial performance of herds that received traditional veterinary services. Financial outcomes were studied during the course of the 2-year program and then reassessed 10 years after the program was completed. The study documented considerable returns during the course of the study, but the positive effect diminished after the program was discontinued.

Partial financial returns from targeted interventions have been documented. One study estimated the impact of free-stall housing on BTSCC values in California dairy herds (Lehenbauer et al, 1998). This study concluded that the BTSCC of herds using free-stall housing was 34,000 cells/ml less than herds that used dry-lot housing during winter conditions. They estimated the improved milk quality resulted in a seasonal benefit of $10.25/cow. Over a 20-year planning horizon, improvements in milk quality alone would account for approximately 36% of the initial building investment.

It is also wise for the veterinary practitioner to be aware of financial limitation that may impact the success of health management programs. Improvements in herd performance may not have much impact on financial performance of the farm family if debt payments consume a considerable amount of farm operating capital.

DISEASE OCCURRENCE RELATIVE TO AGE GROUP AND LACTATION CYCLE

Both the prevention and occurrence of diseases of dairy cattle are linked to age and production cycle. It is therefore logical to assign preventive practices based on the critical high-risk periods for disease. The periparturient period and early lactation are the highest risk periods for most diseases of lactating cows. Many subclinical diseases such as ketosis or subclinical acidosis are related to metabolic and dietary changes that occur during this period. Other syndromes such as subclinical mastitis caused by contagious pathogens and lameness are documented more frequently during middle to late lactation. Diseases that occur later in lactation are often related to longer exposure to contagious organisms or repetitive stresses such as failing to provide adequate cushioning in stall beds. The highest-risk period for youngstock is during the preweaned period. Animals of this age are extremely susceptible to respiratory and enteric pathogens, especially when housed in group conditions. Specific disease control strategies are fully outlined in the appropriate chapters of this text.

Most sporadic clinical diseases have a relatively short duration and have a minimum impact on productivity unless a large proportion of the herd is affected. The long-term impact of subclinical disease is more likely to adversely affect overall herd performance.

Pregnant cow or heifer (during dry period for cow).

1. Select quarters for culture by examining somatic cell count (SCC) or California mastitis test of quarter milk samples 1 month or less before drying off
2. Use appropriate dry cow therapy for mastitis control
3. Vaccinate pregnant dam with *E. coli* J-5 vaccine for coliforms mastitis control and booster as recommended by product label; consider the use of other farm-specific vaccines such as enterotoxigenic K99+ *E. coli*, rotavirus, coronavirus, and sometimes *Salmonella* sp.
4. Perform body condition score (BCS) at dry off and adjust diet as recommended
5. Control cation-anion balance of diet to minimize milk fever; feed low potassium diet
6. Check dietary levels of vitamin E and selenium; supplement animals as needed
7. Trim hooves
8. Dock tails using rubber rings if necessary and allowed
9. Ensure that calving area is clean and dry and is not used for housing sick cows

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Periparturient cow (1 week before and immediately after calving). Observe the cows daily for the following:
1. Udder edema
2. Dystocia, retained fetal membranes, and metritis
3. Parturient paresis and downer cow syndrome
4. Reductions in appetite or rapid changes in BCS
5. Displacement of the abomasum
6. Remove udder hair by trimming or singeing

Early lactating cow (fresh cow; calving to 1 month afterward). Observe the cows daily for the following:
1. Clinical or subclinical ketosis; use appropriate screening tests
2. Lameness
3. Hypomagnesemia
4. Postparturient hemoglobinuria
5. Displacement of the abomasum
6. Cecal dilatation
7. Estrus
8. SCC and clinical mastitis

Middle and late lactating cow (after first month of lactation). Observe the cows daily for the following:
1. Delayed onset of estrus, repeat breeder
2. Pregnancy diagnosis
3. SCC and clinical mastitis
4. Teat lesions such as hyperkeratosis or ulceration
5. Deviations in milk yield related to disease or nutritional program
6. Butterfat and protein tests
7. BCS
8. Trim hooves in mid-late lactation

Newborn calf from birth to weaning.
1. Drovide necessary obstetric assistance
2. Dip navel of calf
3. Supplement with selenium or vitamin E if necessary
4. Assess level of immunoglobulin in colostrum
5. Ensure adequate intake of colostrum by hand-feeding 4 L colostrums
6. Identify calf with ear tag or tattoo
7. Examine for evidence of congenital defects
8. House in individual pen until weaned
9. Feed milk from cows known to be free of Johne's disease and bovine leukemia, or feed milk replacer until weaning
10. Offer hay and calf starter at 2 weeks of age; wean when eating 1 kg of dry feed
11. Ensure adequate vitamin D intake
12. Observe for major problems: acute diarrhea caused by *E. coli*, rotavirus, coronavirus, *Cryptosporidia* sp., and others; omphalophlebitis, infectious arthritis

Calf from weaning to 6 months of age.
1. Provide adequate diet and housing to achieve optimum growth rate and prevent specific vitamin and mineral deficiencies
2. Vaccinate for infectious bovine rhinotracheitis, enzootic pneumonia, bovine virus diarrhea, leptospirosis, clostridial diseases, and salmonellosis
3. Institute ringworm control and control of internal and external parasites
4. Avoid garbage dumps (lead poisoning)
5. Weigh or tape calf monthly to measure if optimum growth achieved
6. Observe for major problems: enzootic pneumonia of calves, infectious enteritis

Heifer from 6 months to 15 months of age.
1. Remove supernumerary teats
2. Provide adequate diet to ensure optimal growth and prevent specific mineral and vitamin deficiencies
3. Ensure adequate housing and stocking density to control infectious diseases such as coccidiosis and intestinal parasites
4. Observe for diseases that are likely to occur, including bovine virus diarrhea, coccidiosis, pneumonia, ostertagiasis and other parasites, papular stomatitis, calf diphtheria (necrotic stomatitis), ringworm, clostridial diseases, and hemophilus meningoencephalitis

DISEASES OF DAIRY CATTLE NOT NECESSARILY RELATED TO THE PRODUCTION CYCLE

Diseases Controllable by Vaccination. These include leptospirosis, clostridial diseases, anthrax, brucellosis (where legislation permits), infectious bovine rhinotracheitis, infectious keratoconjunctivitis, hemophilus meningoencephalitis, and rabies.

Diseases Controllable by Nutritional Management or Supplementation. These include copper deficiency, vitamin E and selenium deficiencies, polioencephalomalacia, calcium, phosphorus, and vitamin D deficiencies, several other mineral deficiencies (e.g., salt, magnesium, zinc), simple indigestion, rumen overload, ruminal tympany, traumatic reticuloperitonitis and allied syndromes, rumen acidosis and laminitis, low milkfat, fat cow syndrome, and primary acetonemia.

Diseases Controllable by Test and Slaughter. These include leukosis, brucellosis, tuberculosis, Johne's disease and BSE.

Diseases Controllable by Medication. These include coccidiosis, intestinal helminthiasis, fascioliasis, external parasites (lice, chorioptic mange), anaplasmosis, ringworm, and hairy heel warts.

Sporadic Diseases Not Warranting Specific Preventive Techniques. These include listeriosis, contagious bovine pyelonephritis, hemophilus meningoencephalitis, actinobacillosis, actinomycosis, bovine papular stomatitis, bovine malignant catarrh, and spondylosis in dairy bulls.

Diseases Controllable by Usual Hygienic Precautions and Improved Animal Husbandry. These include footrot (foot baths), lameness from diseases of the feet other than footrot and hairy heel warts, pneumonic pasteurellosis, winter dysentery, salmonellosis, pseudocowpox, bovine ulcerative mammillitis, ringworm, *Dermatophilus* infection (mycotic dermatitis), and diseases caused by chemical agents (lead, arsenic, fluorine, molybdenum, sodium chloride, hydrocyanic acid, nitrate, insecticides, urea, mycotoxins, dicumarol).

Diseases Controllable by Prevention of Introduction of Infection. These include foot-and-mouth disease, bluetongue, brucellosis, anaplasmosis, tuberculosis, Johne's disease, leptospirosis, and salmonellosis.

Diseases Controllable by Genetic Surveillance. Certain congenital defects in newborn calves can be recognized clinically and pedigree analyses carried out to identify and remove carrier animals.

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CHAPTER 7

Managing Reproductive Efficiency in Dairy Herds

PETER W. FARIN and BARRETT D. SLENNING

Because the cow, like other mammals, produces milk only after giving birth, reproductive management of a dairy herd is central to a dairy farm's overall success in producing milk. The general goal of dairy farms is for cows to produce a maximum amount of milk per day of life at a minimum of feed costs. To do so, cows should calve at regular intervals and therefore must be bred and become pregnant within a given period after calving. If conception is delayed, reproductive inefficiency can lead to milk production inefficiency. Indeed, in the 1950s and 1960s, reproductive services were among the first programs offered by veterinarians. Along with udder health, activities related to reproduction have long formed the foundation services for which the dairy industry finds veterinary intervention useful. As a result, over the past few decades regularly scheduled herd checks have become the most common reason for a veterinary visit to most dairy farms. These visits present an opportunity for in-depth discussions about the herd's reproductive performance and areas of management that affect reproduction and the farm's income. Thus the herd veterinarian must become conversant in several disciplines and expert in several fundamental aspects affecting reproductive efficiency in a typical dairy herd.

This chapter discusses current approaches to the exciting and challenging area of managing reproduction in dairy cattle on the farm. It addresses the needs of the recent graduate veterinarian who is faced with establishing a new herd reproductive program and provides recent information on dairy cattle reproduction to those veterinarians currently engaged in practice. This chapter begins with a discussion of recent trends in reproductive performance of dairy cows. Next, the different reproductive strategies found on dairy farms are discussed, including year-round versus seasonal calving farms and artificial insemination (AI) versus bull breeding programs. Then, diagnostic methods for on-farm reproductive programs, ways to enhance reproduction of the herd and the individual cow, and different strategies for investigating reproductive inefficiency are addressed. Readers who may want more information on specific reproductive problems and diseases of dairy cows are strongly encouraged to consult the relevant chapters in the text by Youngquist (1997a). The next sections of this chapter discuss the different reproductive indexes and approaches for monitoring reproductive efficiency on dairy farms. The chapter closes with a general discussion of the financial considerations affected by reproductive inefficiency.

TRENDS IN REPRODUCTIVE PERFORMANCE AND MANAGEMENT

Little Improvement in Average Performance Over Time

In general, the current level of reproductive performance in dairy herds is well below the published optima. Across the industry, the average days open is 120 to 140 days (calving interval of 400 to 420 days), and the average conception rate is 45% to 50%. In a Canadian study, the reproductive efficiency of artificially bred Holstein cows was as follows: mean services per conception, 1.97; percentage conception to first service, 47%; days from calving to first service, 88; and days from calving to conception, 121 (Tong et al, 1979). In this study the reproductive efficiency was highest in small herds with 35 or fewer cows, and producers who managed their labor efficiently for the production of milk also managed their herd well for reproductive performance. The level of reproductive performance in dairy herds in the United States is also below optimum (Spalding et al, 1975); the calving interval for dairy cows averages at least 13 months in most areas and longer in many states (Hawk, 1979). Data from nearly 5000 Dairy Herd Improvement Association (DHIA) herds in the southeastern United States in 1986 revealed only 43% estrus detection efficiency, 86 days to first breeding, 46% successful inseminations, and minimum average days open of 133 days (calving interval of 413 days; Fetrow et al, 1988). Despite efforts by veterinarians to provide routine reproductive service to dairies, these averages have proven remarkably resistant to change over the past several decades.

Researchers following long-term trends in dairy herd reproductive indexes have recently published troubling findings regarding industry average performance. Silvia (1998) studied the records of 70 Kentucky dairy farms over a 20-year period and reported that the average services per

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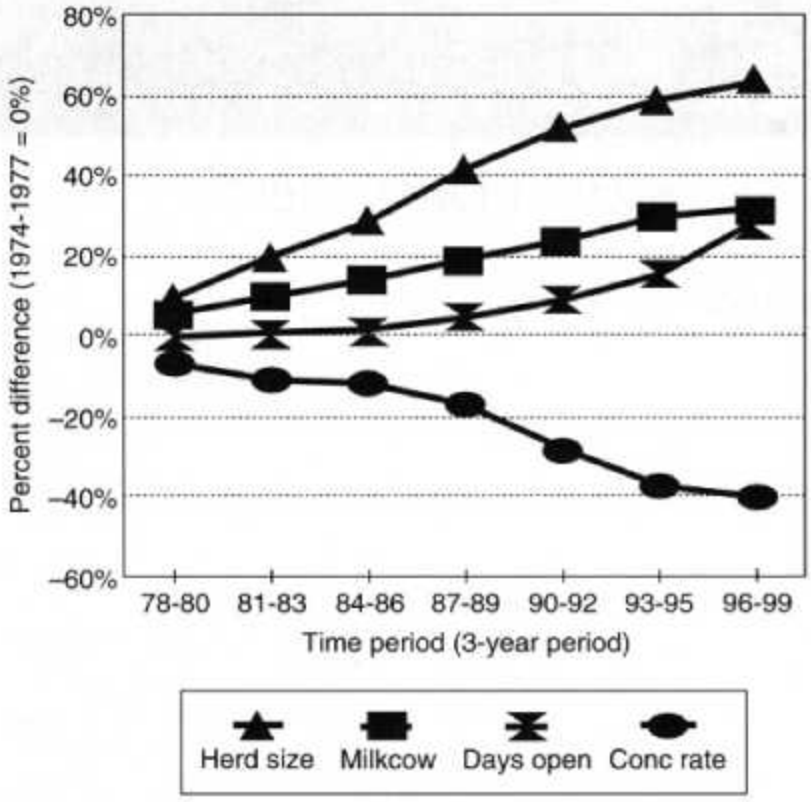

FIG. 7-1 Trends in herd characteristics and reproductive success over 25 years for 338 Southeastern U.S. dairy herds. Values are relative to the situation in the 1974-1977 period. Herd size and production have increased over time, however, reproductive indexes have degraded. (Adapted from Washburn SP, Brown CH, McDaniel BT, et al. In Pritchard DE, editor: Proceedings of the conference on Managing Reproduction in Southeastern Dairy Herds, Salisbury, NC, February 23-24, 2000.)

pregnancy had degraded by 1.29 (2.91 versus 1.62), causing nearly an 80% decrease in performance ([2.91 − 1.62]/1.62 = 0.80) and an estimated conception rate decrease of approximately 56%. Silvia also reported that, over the same period, average days open had increased by nearly 1.3 standard estrus intervals (27 days).

Washburn et al (2000) summarized Dairy Records Management Services data from eight U.S. Southeastern states, comprising the period of 1974 through 1999, for 316 Holstein herds, 17 Jersey herds, and 5 herds of other dairy breeds. The outcomes are shown in Fig. 7-1. Over the period evaluated, and across all breeds followed, herd size increased an average of 64% (from 112 in 1974 to 184 in 1999) and per cow milk production increased by 31% (from approximately 6600 kg in 1974 to 8600 kg by 1999). During the same time, however, average days open increased on average by 27% (from 127 days in 1974 to 161 days in 1999), and typical overall conception rates fell by 41% (from 54% conception rate in 1974 to 32% by 1999). Although the magnitude of effect appears somewhat different in this second study, the larger data set confirms the major trend identified by Silvia (1998): reproductive indexes are degrading on modern dairies.

There are likely several reasons for the loss in reproductive performance. The herds studied by Washburn et al (2000) are from the southern United States and hence may be sensitive to heat stress, and that sensitivity may be greater with increased production and/or herd size (Farin et al, 1994). As has been suggested in numerous studies, there is also a negative relationship between production and fertility, although the practitioner needs to discern between *individual animals* or *herds* when discussing this topic. For instance, in a herd-level situation, the data presented in the next subsection suggests that higher-producing herds perform at least as well reproductively as, if not better than, lower-producing herds. Similarly, a study of over 15,000 cows in 26 New York herds identified milk production as playing a minor role in reproductive outcome (Eicker et al, 1996). However, on an individual animal basis, higher production individuals within a herd are often at risk of lowered reproductive performance. Furthermore, cows selected for high milk production show different characteristics in follicular and endocrine functions that could lead to decreased reproductive efficiency (Nebel and McGilliard, 1993).

Washburn et al (2000) suggest that besides any genetic correlations between milk production and reproduction, the way in which genetic records for bulls are established may actually be rewarding those pedigrees with decreased fertility; the later a cow rebreeds (within reason), the higher milk production indexes she will have in most of the standardized systems. Thus producers may have been selecting inadvertently family lines that breed later, making the job of maintaining high reproductive performance more difficult. Again, the cause of the industry's degrading performance in reproduction is likely multi-factorial: genetics, nutrition, facilities, reproductive practices and technologies, and financial factors have probably played a role. The important point is that whatever the reason for this decline in reproductive performance over time, it appears to be real, and it will make careful management of reproduction even more important in the future.

The decline in reproductive performance forces everyone in the profession and industry to reconsider what we are doing and why. If, after a few decades of reproductive services and production medicine, reproduction is degrading on the average dairy farm, practitioners need to look closely at their role in this diminution. Perhaps the industry has encouraged evaluation of indexes that are actually inappropriate for long-term performance improvement. It is possible that this apparent loss of performance is causing an actual overall improvement in dairy herd stability and efficiency; prior goals based on maintaining short lactations and calving intervals may no longer be appropriate. However, even if this "rose-colored glasses" view of the data were correct, it is still troublesome that the industry's efforts to accomplish a different result are seemingly ineffective. Perhaps producers focus on short-horizon, individual-based decisions that paradoxically work to damage herd-level outcomes. They might be encouraging activities and practices that, while meeting the needs of individual animals or individual animal-classes, is limiting the performance of the herd; breeding that "good" cow yet another time may perpetuate genetic and management factors within the population that, over time, harms the population. Other possibilities exist. However, practitioners must be aware of the problem and must be willing to look in a new light at the entire system surrounding dairy cow reproduction, including their efforts and goals.

Regional and National Baseline Data

U.S. Department of Agriculture, National Animal Health Monitoring System Data

In 1996 the U.S. Department of Agriculture's National Animal Health Monitoring System (USDA/NAHMS) assessed multiple factors in dairy herd health and productivity by surveying over 2500 producers from the top 20 dairy-producing states (approximately 83% of U.S. milk cows). The data were sorted by breed, herd size, and production. The following discussion pertains to the information extracted for dairy herds completely comprised of Holsteins, as summarized in Table 7-1.

Several trends can be identified from Table 7-1. First, it appears that as herd size increases, so does production, on-

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TABLE 7-1

Association of Management Practices with Herd Size and Relative Milk Production

		Herd Size							
		30-99 Cows		100-199 Cows		200-499 Cows		500+ Cows	
		High	Low	High	Low	High	Low	High	Low
Maximum milk/cow (kg, rounded to nearest 100)		8800	7000	9100	7500	9500	7400	10,000	8300
Participant herds	Number	247	256	95	97	66	69	38	38
	Total (%)	27	28	10	11	7	8	4	4
Pasture cows		47	70*	17	49*	15	42*	3	21*
Is Dairy Herd Improvement Association participant (%)		81	22*	79	22*	82	29*	74	47*
Uses on-farm computer (%)		20	6*	33	14*	58	28*	92	55*
≥50% of cows exposed to prostaglandin programs		11	4*	18	5*	29	1*	24	16*
Uses break-even milk production in culling decisions		35	22*	46	32*	62	38*	82	58*
Uses veterinary reproductive consultation		90	67*	90	75*	89	77	95	82
Reproductive vaccinations used	BVD	90	57*	92	76*	96	75*	90	87
	IBR	88	56*	87	74*	94	77*	76	90
	Hemoph	53	25*	56	37*	59	44	42	61
	Lepto	84	61*	86	74*	92	78*	90	95

BVD, Bovine viral diarrhea; *Hemoph*, hemophilus; *IBR*, infectious bovine rhinotracheitis; *Lepto*, leptospirosis.

Data are from the 1996 U.S. Department of Agriculture National Animal Health Monitoring System Dairy '96 report, *Management practices associated with high-producing U.S. dairy herds*. Data are reported according to the highest-producing 25% of participants *(High)* and lowest-producing 25% of participants *(Low)* within each of four herd-size categories.

*Indicates the difference observed between "High" and "Low" quartile producers is statistically significant ($P \leq .05$). Statistical significance not reported for the interquartile differences; however, average production for the herd size categories suggests the small herds had lower production, the largest herds had the highest production, and each was significantly different from the two middle herd-size categories.

farm computer ownership, use of prostaglandin (PGF)-based reproductive programs, and consideration of break-even milk production in culling decisions. The use of pasture-based feeding appears to decrease as herd size increases. It is also apparent that, within herd size categories, the highest quartile producers are statistically more apt to use nearly all of the practices shown in Table 7-1 than are their lowest quartile peers, until the individual vaccinations in use are examined. This is especially true for herds with fewer than 200 cows; in these herds the top quartile producers had adopted each listed practice to a significantly higher degree ($P \leq .05$) than had the lowest quartile producers. The exception is in the pasture use index, wherein the relationship was the reverse: across herd sizes, a significantly higher proportion of lowest quartile producers use pasture than do their highest quartile peers.

Once herd size exceeds 200 cows, the picture is not as clear. For instance, it appears that, in the largest herds, there may be a trend of decreasing use of DHIA records systems. This is likely due to the very large herds being able to amortize the costs of custom-reporting systems with their own on-farm systems (note that the lowest quartile producers in the "500+ Cows" category reported a higher level of on-farm computer use than did even the highest quartile producers in the categories of less than 200 cows). The picture is similar regarding veterinary involvement in reproductive consultation. There is a significant difference in utilization between the low-quartile and high-quartile producers when herd sizes are less than 200 cows (with the highest-quartile producers more apt to use veterinarians for reproductive consultation), but not so in the larger herds. In this index, there is little apparent difference across herd size categories in the utilization rates of the high-quartile producers. The picture for vaccination use also shows an interesting herd-size effect. Apparently, once herd size reaches a certain point, it becomes standard practice across quartiles to use the reproductive vaccines identified, though paradoxically it seems that a trend exists whereby the highest quartiles use these vaccines at a *lower rate* than do their lowest-quartile peers. The reasons for this finding are not clear.

Dairy Herd Improvement—Provo Regional and Production-Based Data

One of the DHIA's records processing center, DHI-Provo, had approximately 10% of the U.S. herds and 19% of the U.S. cows enrolled in its varied test plans, as of January 1999 (Wiggans, 1999). The center publishes regional data on its

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TABLE 7-2

*Regional-Based and Herd-Production-Based Comparative Baseline and Reproductive Data**

	Region			Weighted Averages				
	East	North-west	South-west	All	High†	Mod High	Mod Low	Low
PARTICIPANT HERDS								
No. of herds	1203	805	317	2325	755	562	535	473
Total (%)	52	35	14	100	32	24	23	20
PRODUCTION								
RHA milk (kg)	9080	10,058	9697	9503	10,661	9363	8519	7227
Milk (milking) (kg)	27.9	31.5	30.6	29.5	32.8	29.2	26.7	23.0
REPRODUCTION								
DIM	208	199	202	204	205	202	205	205
DIM, first breeding	89	84	79	86	83	84	89	95
Days open	150	145	144	147	145	146	150	155
Preg. first service (%)	46	45	42	45	43	44	46	54
Services/conc (preg)	2.17	2.23	2.37	2.22	2.27	2.32	2.12	1.93
Detected heats (%)‡	na	na	na	49	52	50	48	43
Calving interval (last)	14.1	13.8	13.7	13.9	13.9	13.9	14.1	14.1
Calving interval (next)	14.1	13.9	13.8	14.0	14.0	14.0	14.1	14.2
Days dry	63.0	64.0	66.0	63.8	63.0	63.8	63.9	67.1
Avg. age at calving	27.1	26.7	26.6	26.9	26.1	27.1	27.5	28.4
LEFT HERD								
Avg. leaving herd (%)	37	36	34	36	36	38	35	37

*For U.S. dairy herds subscribing to the Dairy Herd Improvement—Provo dairy records processing center for 1997. Significant associations are found between rolling herd average milk production *(RHA)* and the indexes of days in milk *(DIM)* at first breeding, days open, % detected heats, and average age at calving (all show $P \leq .05$). Data adapted from DHI Computing Service, DHI-Provo. Available at http://www.dhiprovo.com/vetzone (accessed October 23, 2000).

†Categories of relative herd-average milk production.

‡Extrapolated from same source (Holstein Report 160: Percent of Detected Heats), which does not list regional data.

Internet site that is adapted and summarized in Table 7-2. The table addresses several baseline and reproductive data points on both a regional basis and by relative milk production. No information is given as to the statistical significance of any of the apparent differences. However, it appears that the eastern region of the United States tends to have lower milk production, increased days in milk, increased days in milk at first breeding, more days open, increased calving interval, older average age at calving, and a higher culling rate than the other two regions listed.

In addition to the information just given, the trends in milk production suggest that days in milk at first breeding decrease as rolling herd average milk production goes up (decreasing approximately 3 days for each 500-kg increase in rolling herd average; $P = .05$). Furthermore, there is a concomitantly strong association between rolling herd average and days open (decreasing approximately 1.5 days for every 500-kg increase in rolling herd average; $P = .04$), according to the DHI-Provo data in Table 7-2. Percent of heats detected displays a similar statistically significant association with rolling herd average (a 500-kg increase in rolling herd average is associated with just over a 1% increase in percent heats detected; $P = .03$). Age of the herd also appears to be associated significantly with rolling herd average ($P = .02$), although here it is a negative association. Although it appears that services per conception for pregnant cows decreases as rolling herd average decreases, it is not statistically significant using the DHI-Provo data ($P = .12$). The same is true for the percent pregnant at first service ($P = .08$). Finally, no linear association appears to exist between rolling herd average production and culling levels ($P = .91$).

The conclusion from the DHI-Provo data is that higher production on a herd level is associated with decreased days in milk at first breeding, days open, average age at calving, and increased percent of detected heats. Based on these data it is not possible to determine whether the increased milk production drives the reproductive performance data or whether the reproductive trends are driving milk production. It simply may be that quality dairy management is able to achieve both high milk production and good reproductive performance simultaneously. Finally, the DHI-Provo data also suggest that a veterinarian might expect to see regional differences in both production and reproductive performance.

National Databases and Future Reproductive Performance

The USDA/NAHMS data allow practitioners to make several predictions about the clientele now and in the future. If we assume that the index on pasturing cattle captures, to a

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major degree, a representative sample of seasonal breeding herds in the United States, then veterinary intervention in these herds faces several difficulties. These herds tend to be small and low producing, and therefore are less likely to adopt advanced practices in records systems, endocrine management of reproduction, vaccination programs, and use of veterinarians in consultative positions.

The USDA/NAHMS data suggest that the initiation of high-end consultative, production medicine-based, reproductive programs generally will be less apt to be adopted or to succeed on smaller and lower-producing farms. Unfortunately, as with many factors of dairy management, these farms are also the farms that often most need such services. This situation has been a factor in the industry throughout history. The marketing quandary this places before dairy veterinarians, therefore, is not likely to go away for a long time.

The USDA/NAHMS data imply that larger herds are more apt to adopt reproductive technologies and are more likely to intensively manage their cows. This also means that such farms may be more likely to recognize the value of preventive work and veterinary consultation (except, apparently, when vaccination programs are considered). Here, it seems that larger, higher-producing herds are showing a trend of less vaccination use. Perhaps these farms cannot make these programs "pencil out." Perhaps these managers feel they can depend on better overall cow health and biosecurity rather than on vaccination. Either way, this indicates that a major tool of the production medicine veterinarian is losing its appeal in the large, high-producing herd. If this is true, and the direction of the industry is toward the larger, higher-producing herds, it promises to make life a bit more difficult for those veterinarians unaccustomed to justifying their recommendations on other than a strict biological basis.

The DHI-Provo data complement the USDA-NAHMS data, because they suggest that increased milk production and reproductive performance go hand in hand. Biologically, it makes sense that poor reproductive performance tends to decrease average milk production per cow. It also seems a reasonable assumption that those managers who are adept at managing cows for high production are also likely to be able to successfully manage a reproductive program. It is tempting to assume that this relationship between increased production and improved reproduction is accomplished by the similar trend in increased veterinary input witnessed in the USDA-NAHMS data. But that is only speculation.

The reader needs to be aware that no segment of the dairy industry is a monolith; there will be high quality dairies, and there will also be poor managers in each of the identified subgroups. Never assume that because a farm is relatively small, or relatively low producing, that the management is proportionately below average. The practitioner need only walk onto a small, low-producing, seasonal grass-fed dairy that is also achieving four times the net income per unit milk than its confinement-reared neighbors to recognize this is true. Likewise, being big and high producing does not guarantee high-quality management. As the twist on the old saying goes, ". . . The race may not always go to the swift, but it is the best way to bet. . . ." So, while the previous comments are perhaps overly broad in their scope, they bring out issues of which veterinarians and the dairy industry need be aware. We need to recognize that these general trends exist.

REPRODUCTIVE DISORDERS AND CULLING

Reproduction is the primary reason given for why cows are culled in modern dairies (Bascom and Young, 1998), accounting for 20% of all primary culling reasons, and approximately 10% each for all secondary and tertiary culling reasons. Bascom and Young (1998) also found that reproduction became a more important culling factor as herd production rose. It should be noted that it is unlikely that all of these cows culled for reproductive reasons were truly infertile.

Reproductive culling is actually an amalgamation of culling because of several disorders (infectious, metabolic, and traumatic), each of which negatively impact reproductive efficiency (Gröhn et al, 1998). In addition, it has been long recognized that the differing reproductive problems are interrelated. For instance, one study followed 2850 Holsteins from 33 New York herds and looked at reproductive diseases and culling (Erb et al, 1985). In this study cows experiencing dystocia were also nearly three to four times more likely to suffer retained fetal membranes, metritis, and culling; they also averaged over 7 days longer to first service than did cows not experiencing dystocia. Cystic ovarian disease, in this study, was associated with an over-16-day delay in first service. Overall risk of culling was increased by reproductive disorders by a factor of 2 to nearly 4. But the culling picture is often not so cut and dry. In a study of Swedish cows (Emanuelson and Oltenacu, 1998), researchers found that animals suffering from some disorders may have actually been "protected" from culling, depending on the herd's overall level of milk production; cows with apparent anestrus are nearly 20% less likely to be culled in herds at the lower quartile of production, whereas apparent anestrus is essentially a nonfactor in culling for herds in the highest quartile of production. (The relevant results are illustrated in Fig. 7-2.) It is likely that dairies are willing to "put up" with poor reproductive performance if milk production is high. This makes the control of reproductive disorders much more complicated.

To add to the importance of controlling reproductive disorders on dairies, Peeler et al (1994) found that several reproductive disorders showed a relatively high risk of recurrence for nearly 1500 pairs of successive lactations in Great Britain. Hence reproductive failure is the most common cause of culling, and most reproductive disorders are risk factors for other reproductive problems and for other health problems. Once a cow experiences one type of difficulty, assuming she is not culled, she is at higher risk of the same problem in the next lactation.

SEASONAL AND NONSEASONAL DAIRY PRODUCTION

Different Goals, Different Drives

Perhaps the most common example of a seasonal producing dairy is an intensively grazed, grass-fed farm. These systems, once the only means of producing milk worldwide (and still the system of choice in areas such as New Zealand), began to fall into disuse across parts of Europe, the Americas, and the industrialized sections of Asia and Africa, from the 1930s up until fairly recently. The ability to manage grass and cows has improved, however, and along with changes in the economics of dairy production, these improved abilities have created a new interest in this type of production.

In seasonal herds cows must calve at the time of year best suited to the needs of the particular herd to meet milk quotas or when supplies of feed are at their most plentiful and best able to supply the nutrient demands of lactation and pregnancy. As a result, they may have as little as 6 to 8 weeks to breed the entire herd successfully to match it to the desired calving season. Cows that do not meet this goal are usually at increased risk of culling. In some situations, rather than cull the cow, the producer may opt to actively induce abortion in a cow with PGF or a glucocorticoid-PGF protocol to force her to "calve" at the optimal time of year. Neither option is good. Forced culling of cows can play havoc with genetic improvement and puts extreme stress on a

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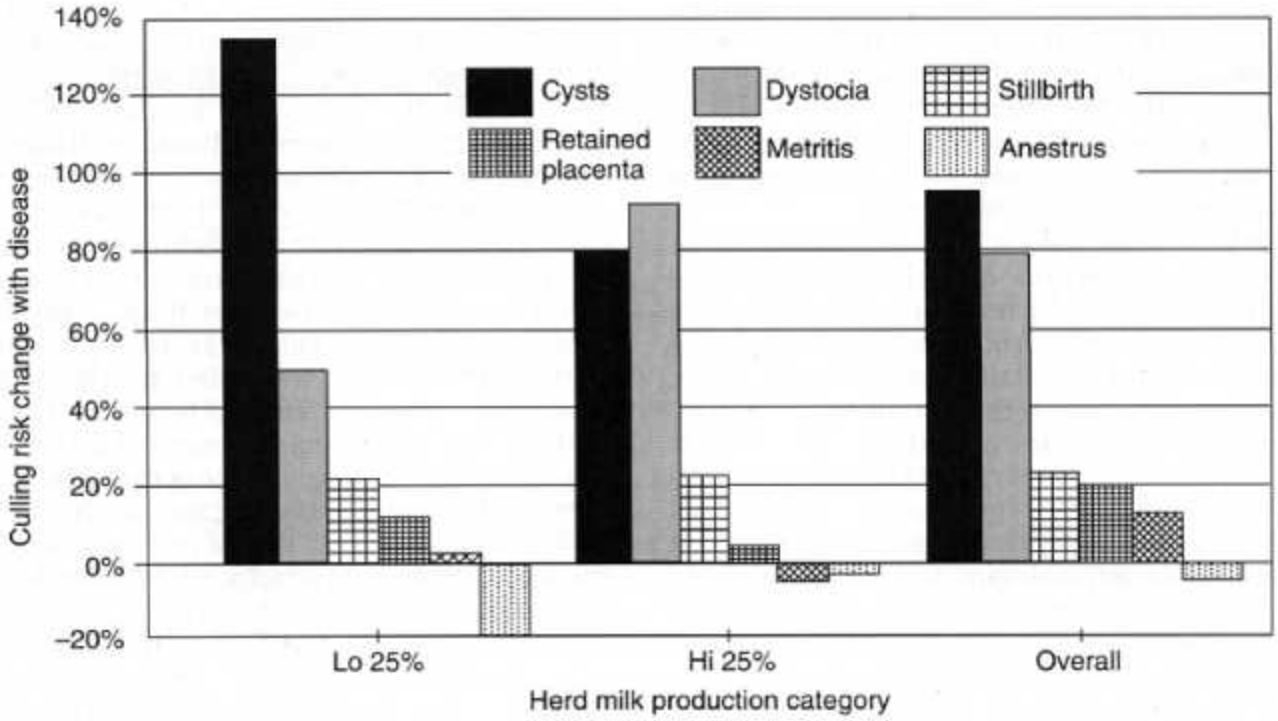

FIG. 7-2 Effect of reproductive disease on culling risk for Swedish dairy cows, based on the lowest quartile of herds by milk production *(Lo 25%)*, the highest quartile *(Hi 25%)*, and overall levels of milk production *(Overall)*. Total number of herds = 1090; total number of cows = 33,748. (Adapted from Emanuelson U, Oltenacu PA: *J Dairy Sci* 81:2376-2382, 1998.)

herd's youngstock program. Induced abortion of cows also stresses the youngstock program and leads to concerns of animal welfare, because often the premature calves are born alive or calves may be euthanized at birth. Again, neither option is acceptable as a long-term reproductive strategy. Hence, it becomes essential for a seasonal herd to achieve its optimal breeding window, which translates into a 12-month calving interval.

The most common type of dairy in North America is not a seasonal grass-fed dairy but a nonseasonal confinement-reared dairy. In such a dairy, feeds in the form of a mixed ration are brought to the cows. Throughout the year feeds are stored on farm, making the dairy relatively indifferent to the growing season. As a result, most such herds practice year-round calving. The practitioner must understand, however, that because of market actions, many of these farms will have times of the year when calvings are more concentrated than at others. For instance, throughout the eastern part of the United States, milk pricing is such that dairies are "rewarded" for producing milk in the autumn. The "reward" may be higher prices, or it may take the form of setting the basis for total amount of milk the dairy may sell at other parts of the year at a given price. Either way, the farmers are prodded to produce in the fall. The important difference between this type of seasonality and that of the grass-fed dairies is that, should a cow miss getting bred in time to calve in the autumn, the cow is not necessarily at greater risk of being culled. The dairy simply suffers an opportunity cost of the postponed calving; the dairy foregoes some added income by missing the best calving time.

There are other drawbacks for a year-round calving herd when cows are not bred on time. Cows' daily milk production decreases as the time from parturition passes (increasing days in milk). The producer has two options for a cow with delayed conception: either dry off the cow and allow a long dry period, or continue to milk the cow with reduced daily milk production. Neither option results in as much average milk per day as would have been possible if the cow had conceived at a proper time postpartum. In nonseasonal herds, the fundamental economic purpose of a reproductive program is to minimize the variation in lactation lengths and keep them at an appropriate length without prolonging the dry period. Other economically important objectives of reproductive programs are reduced culling because of reproductive inefficiency, reduced need for treatment of reproductive disease, increased genetic selection opportunities, and earlier first calving in heifers.

Different Strategies, Different Optima

It should be apparent that one of the main differences in reproductive strategies between seasonal and nonseasonal farms is that the former *must* achieve a 12-month calving interval to survive, whereas the nonseasonal herd has more leeway in determination of an optimum calving interval. Although a calving interval of 12 months has been associated with yielding the optimum amount of milk and number of calves over the lifetime of the cow in a nonseasonal dairy (de Kruif and Brand, 1978), it is likely that, for high-producing herds, the optimum interval is longer than 12 months.

Part of the difficulty in interpreting most research on calving intervals is that the economic return of individual systems is confounded by the abilities of individual dairy managers and by the reproductive goal the dairy is attempting to achieve. For decades, extension agents, dairy science professors, consultants, and veterinarians have been telling producers that a 12-month calving interval is optimal (Wells and Burton, 1981; O'Conner, 1993). Dairies that reach this goal most consistently are usually the dairies with the best managers. Furthermore, these "best reproductive managers" are likely also better at other aspects of running a dairy, such as cost control and finances. Hence, it is not surprising when a study finds that the farms reaching a 12-month calving interval are also the highest profit farms—indicating that efficient reproduction is usually a good proxy measure for an overall well-run dairy. However, most studies cannot show whether those same farms would have done even better economically had they opted for a longer or shorter calving interval. Another confounder to most calving interval studies is that herds that achieve a long calving interval were

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likely attempting to reach a 12-month interval. Hence, they will have experienced most of the expenses involved in making the 12-month calving interval—with another 2 months' worth of estrus detection labor, hormonal manipulation, and semen—yet will have generated the lowered average income from the longer interval. Therefore the researchers prove not that a *planned* 14-month calving interval is worse than a 12-month interval, but that a farm that misses its goal by 60 days does worse than a farm that does not miss its goal. Again, this is not surprising. Finally, survey-type research, of necessity, treats many inputs as constants across levels of production and herd size. This means that feed and feed costs, for example, are assigned as constants per unit of milk produced, in essence making milk production immune to economies of scale or increases in efficiencies. Since both of these are primary goals of growth and increased production, these types of studies will inappropriately discount such management practices.

Some researchers have attempted to get around the limitations just mentioned, either through whole-farm clinical trials or through computer modeling and simulation. As an example of the former study type, Holman et al (1984) established programs to achieve different lengths of monthly calving intervals in Israeli dairies, thereby avoiding the second of the above confounders to most calving interval research. They found that a 13-month calving interval developed higher income per cow than did a 12-month interval. Furthermore they found that, if planned, incomes per cow did not significantly decrease until beyond a 15-month calving interval. As an example of the latter study type, Slenning (1986) demonstrated that in the typical large herd situation in California, optimum calving intervals lengthened with increased lactational production. He further demonstrated that significant losses were associated with calving intervals that were shorter than optimal, but that losses for calving intervals up to a few months longer than optimal were relatively small. The conclusion here was that if a producer were to minimize risk, the appropriate strategy would be to avoid *shortened* intervals, not lengthened intervals. But perhaps the most important lessons from these two studies (and similar work) is that optimal calving intervals are dairy specific and that there are no surefire goals applicable across the board in nonseasonal herds.

BREEDING PROGRAMS: ARTIFICIAL INSEMINATION AND BULL BREEDING

Since the inception of the AI industry in the late 1930s, bull breeding of dairy cows has decreased. The reasons for this trend are many, but they can be mostly explained by a few salient points. First, in most parts of the world AI offers a producer the best genetic improvement possible. Bulls that enter commercial bull studs for AI use are derived from the very top, and most heavily researched, genetics in the individual breeds. In contrast, bulls purchased locally or raised internally on a farm cannot usually compete genetically with those offered by bull studs. Second, the use of bulls in a dairy's reproductive program requires different facilities than one that does not use bulls. For instance, bulls should be rotated for reasons of libido and body condition. Hence a dairy should have pens for bulls that are not breeding currently. In addition, because of their size and aggressiveness, bulls usually require more stout fencing than do cows. Third, AI largely eliminates the transmission of venereal diseases; indeed, it is the recommended treatment modality for many sexually transmitted diseases. Furthermore, bulls, because of their size, can injure older or smaller cows. Hence there are human and cow health concerns with bulls. Fourth, the capabilities of the average dairy farmer have increased over the past decades. Most dairies now have at least one member of the management team with a college degree, and some dairies have management-level personnel with a Master's level of training. In addition, some clients' management include Ph.Ds and lawyers. Such highly trained individuals can make good use of the technical aspects and data-intense methods needed to maximize the value of AI protocols. Finally, on-farm safety is a growing issue on dairies with bulls. As herds become ever larger, and more and more of the work force is hired help, a farm's liability in the case of worker safety and bulls becomes an increasing concern. Future insurance costs may make bull breeding a financially unsound strategy because of risk.

Strengths and Weaknesses of Different Breeding Systems

The vast majority of commercial dairies operate their reproductive program as (1) an exclusively AI system, (2) exclusively bull-bred system, or (3) an AI-bull hybrid system. We will briefly look at the strengths and weaknesses of each system.

Artificial Insemination–Exclusive Herds

For dairies that opt to breed cows solely through artificial means, the advantages are primarily gained through genetic gain and from not having bulls on site. These dairies' potential for genetic improvement is maximized. In addition, commercially available bulls are evaluated for a variety of their daughters' characteristics, from conformation through milk production and milk quality as well as lifespan, economic returns, and disease status. Thus producers can weigh the type of genetic progress to fit the current needs of their herd. This allows mating to be chosen for individual cows—mating that improves on the cow's weaknesses and takes advantage of her strengths. Furthermore, dairies that do not use bulls tend to have lower needs and costs for facilities and fencing in terms of construction and maintenance. In addition, herds using only AI for breeding avoid the costs and dangers of bulls, whether those are measured in terms of disease transmission in the herd or of worker health and safety.

AI is not problem free. First and foremost, AI depends on humans to determine when a cow is receptive (estrus detection) and to deliver live semen to the cow during the short period during which the cow can conceive (breeding technique and timing). Numerous authors have identified estrus detection as the weakest link in dairies' reproductive programs, a link that may explain the majority of economic losses from reproductive failures. In addition, estrus detection can be tedious and time consuming; it is often easy for people to rationalize why some other task(s) should take precedence in their workday. Furthermore, individuals who have the knowledge and skills to properly and consistently perform the tasks involved in AI tend to command some of the highest salaries within the industry. Finally, a growing concern in the AI industry is the resulting genetic concentration that occurs within dairy breeds. It is not uncommon, for instance, for the most widely used bulls in a breed to be related; some are half brothers. Such concentration brings with it a potential loss of genetic diversity and the amplification of genetic afflictions. In fact, the industry already has seen certain genetic problems (bovine leukocyte adhesion deficit, for example) appear over the past few decades. While the industry is actively monitoring for such diseases and establishes tests for the same as soon as one is identified, AI increases the potential for such abnormalities to become widespread in the dairy cow.

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Exclusively Bull-Bred Herds

The advantages for bull breeding primarily relate to the bulls' ability to accurately detect cows in estrus better than any human-based system and to deposit semen at the most appropriate time in a cow's estrous cycle. Bulls happily work weekends, nights, and holidays; they do not ask for vacations or pay raises. In short, they are usually enthusiastic workers that need little to no training or guidance in performing their jobs.

Bull-bred herds have particular problems. Bulls will not record the breedings they accomplished; it is left to the human managers to do this. This requires monitoring estrus behavior, just as with AI herds. In fact, many of the other published difficulties with bull-breeding strategies are not the fault of the bulls, per se, but the fault of lack of management. For instance, some dairies place bulls in the milking herd or in with their breeding-age heifers and then ignore them for weeks or months. This assumption that the bull is able to perform is the likely cause of more reproductive disasters in bull-bred herds than any other factor.

Actual bull-based, as opposed to management-based problems, are plentiful. First, bulls can spread venereal disease such as campylobacteriosis and trichomoniasis. In addition, bulls display varying levels of libido; therefore some bulls are simply less aggressive in breeding than others. Even those bulls with high libido can have feet or leg problems that limit their serving capacity or ability to correctly identify, mount, and breed a cow. Bulls that have injuries to the reproductive tract, especially injuries to the testicles and scrotum, can have lowered semen quality, either short term or long term. Hence a producer may see the bull-breeding cows but may not be aware that semen quality is too low for acceptable levels of conception to occur. Furthermore, bulls usually gain excess body weight on a typical milk-cow ration. Heavy bulls tend to be less active reproductively. As a result, the manager who assumes all is well in a bull-bred herd can easily suffer months of poor performance until the problem is recognized. By then it may be too late for many of the herd's cows to be saved.

As previously mentioned, the typical dairy bull's size and temperament also requires the dairy to experience increased housing and facility expenses as well as increased health and safety concerns. Why dairy bulls seem to be more dangerous than beef bulls is likely due to a combination of factors. However, dairy bulls are creatures that command respect and constant vigilance from the people who work around them.

One bull-breeding system that has become less common on dairy farms is the "hand-mating" system. In such a system, a dairy's management performs estrus detection, as would be normal for an AI herd. However, when a cow is identified as being in estrus, she is moved to a bull pen (typically a small pen in which a single bull lives). The cow is observed to be bred and is then returned to the herd. The advantages of this system are that bull weight and libido can be monitored more effectively, safety of personnel is improved, and facility expenses are usually decreased. The disadvantages, however, are that the system requires intensive estrus detection on the part of management and suffers from lower genetic performance of all bull-based systems. Thus a hand-mating system combines the worst of both systems.

Artificial Insemination/Bull-Breeding Hybrid Systems

Large dairy herds often use a hybrid system comprised of both AI and bull breeding. Cows are usually exposed to AI-based breeding during early lactation, and then they are brought to a "clean-up bull" pen. For instance, a herd might set a limit for days in milk or number of AI breedings for cows, beyond which the animal goes to a milking string in which the clean-up bull resides. The protocol might be that every cow is moved to the clean-up bull pen after being bred three times by AI or after she passes 100 days in milk, whichever comes first. These hybrid breeding systems take advantage of the positive qualities of both AI and bull breeding. Every cow gets a chance to be bred to an AI bull, thereby maximizing the genetic potential of her offspring. In addition, those cows not conceiving to AI are also submitted to the clean-up bull's intensive estrus detection and breeding capability, thereby maximizing their chances of becoming pregnant in a timely fashion. As a result, such herds enjoy the advantages of both systems. In addition, they do not hamper the bulls' ability to detect estrus and to breed on time, as do the "hand-mating" systems.

Unfortunately, a hybrid AI/clean-up bull system carries most of the disadvantages of either individual system. Dairies using the hybrid breeding system have increased expenses in highly trained labor for AI, plus in facilities and maintenance for the bulls. In addition, the herd may suffer from poor estrus detection when cows are in early (and likely optimal breeding window) lactation; they could also suffer from poor breeding performance resulting from a mismanaged bull. There also appears to be a threshold herd size to allow a combined, or hybrid, system to be successful. It is our experience that herds smaller than 350 milking cows will often not be able to group cows effectively enough to make a hybrid system worthwhile.

REPRODUCTIVE EXAMINATION OF COWS

Accurate and easy-to-follow reproductive records are critical to a sound reproductive program. There are several types of record-keeping systems for reproductive data of individual cows ranging from cow cards to computer-based recording programs. Reproductive indexes and strategies for analysis and monitoring of herd-level reproductive data are discussed later in this chapter. The following section presents an overview of on-farm physical exam and laboratory methods for evaluating reproductive system. Palpation of the reproductive tract per rectum remains the most common on-farm technique for assessment of reproduction in cows. In addition to palpation, we discuss the use of ultrasonography and other diagnostic methods, such as progesterone assays, that can provide additional information for the practitioner.

Regular Herd Evaluations

Reproductive performance of the herd can be evaluated monthly, biweekly, or even more frequently in large herds. To achieve optimum herd reproductive performance, it is necessary to obtain optimum performance from each cow. Usually, this requires that each cow calve as close as possible to every 12 to 13 months, beginning at 24 months old. Achievement of that objective depends on breeding cows to conceive by an average of 85 to 120 days after calving. Three important points of procedure are involved:

1. The routine, systematic evaluation of the herd's reproductive status and attention to management activities that impact on reproduction.
2. The concentration of reproductive management activity during the postparturient period and up to 3 months later.
3. Regular physical examination of the cow's reproductive tract.

The achievement of an acceptable calving-to-conception interval (e.g., 85 to 120 days) necessitates concentrated management activity during the first 90 days after calving. In gen-

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eral, early postpartum breeding in dairy cows results in more calves and higher milk yield per day of herd life. However, early-bred cows usually require more inseminations per conception. Breeding normally can begin at about 45 days postpartum with an acceptable rate of reproductive performance, and, with current management practices, a desirable calving interval can be achieved by shortening the interval to first insemination to about 50 to 60 days postpartum. Each day of delay beyond the optimum calving-to-conception interval of 85 to 120 days often reduces the farmer's profit margin (Olds et al, 1979). Each dairy farm, and often groups of cows within a dairy, has a different optimum calving-to-conception interval. The practitioner is encouraged to determine the optimum interval from calving to conception for the dairies that he or she may service.

Reproductive Examination by Palpation

Good palpation skills are an invaluable aid to the practitioner who is initiating a new reproductive health program or maintaining an existing program for a dairy. Emphasis is on the examination of cows for pregnancy, cows that are not detected in estrus by a certain time after calving, cows that experienced calving difficulty or other postpartum problems, and cows that fail to conceive following multiple inseminations. Palpation per rectum of the reproductive tract for monitoring normal uterine involution and ovarian activity is usually done one or more times before the initiation of breeding (Mortimer et al, 1997). Palpation at approximately 35 days or more after insemination is commonly used to diagnose pregnancy in cows and heifers (Youngquist, 1997b). Cows should be examined again to confirm pregnancy status one or more times before the expected dry-off date. Detecting pregnant and open cows and identifying normal and abnormal changes of the uterus and ovaries provide important information for making clinical and management decisions.

Ultrasonography

Ultrasonography is a valuable aid for early diagnosis of pregnancy, determination of fetal sex, and accurate identification of uterine and ovarian structures. The potential economic benefits of including ultrasound as a routine procedure in reproductive programs should be evaluated for each individual herd. We anticipate that the use of ultrasound units on dairy farms will continue to increase as the cost of ultrasound units decreases and the units become more adapted for use under a variety of herd conditions. A good quality portable ultrasound unit with a 5.0-MHz probe works well for general reproductive examinations of the uterus and ovaries of cows and heifers. A more detailed examination of ovarian structures may be achieved with the use of a 7.5-MHz probe.

Several conditions of the uterus and ovaries may be assessed with the aid of an ultrasound unit. The developing bovine conceptus can be detected using real-time ultrasonography by at least 19 and 24 days of gestation (Curran et al, 1986); however, diagnosis of pregnancy by ultrasound in large groups of cattle under farm conditions can usually be accomplished in large groups of dairy cows after Day 25 or 26 of gestation. The fluid-filled uterus of the early pregnant cow appears mostly black or anechoic. Because of normal fetal loss, cows diagnosed pregnant at this early stage of gestation should be examined again after Day 60 of gestation to confirm pregnancy. Phenotypic sex of the fetus can be determined through the use of an ultrasound to visualize the location of the genital tubercle, which is the presumptive clitoris or penis (Curran and Ginther, 1991). Fetal sex determination may be performed at approximately 55 to 100 days of gestation, with Days 60 to 80 of gestation being our preference. Ultrasonography may also be used to determine the number of fetuses *in utero* as well as the viability of the developing fetus based on fetal movement and heart beat. Early identification of fetal gender and viability provides the producer with additional information for making decisions about selection and selling of dairy animals. Ovarian follicular waves and corpus luteum (CL) development associated with the normal estrous cycle (Pierson and Ginther, 1988) as well as ovarian cysts may be detected using ultrasonography (Edmondson et al, 1986; Farin et al, 1992). In addition, pathological conditions of the uterus such as pyometra may be visualized with ultrasonography (Fissore et al, 1986).

Other Diagnostic Tests

Progesterone Assays

The most commonly used on-farm assay for progesterone is an enzyme-linked immunosorbent assay (ELISA) for progesterone concentration in milk. In addition, several diagnostic laboratories provide services for determining concentrations of progesterone as well as other reproductive hormones in serum or plasma samples of cows using a radioimmunoassay (RIA). Progesterone is secreted from the CL on the ovary of the cow during the luteal phase of the estrous cycle and during pregnancy. In nonpregnant cows, progesterone concentration in milk is low on the day of estrus (Day 0), gradually increases to about Day 7 of the estrous cycle, remains elevated during the luteal phase, and then decreases following CL lysis on about Day 18 after estrus. In pregnant cows progesterone concentrations remain elevated. Thus concentrations of progesterone in samples of milk, serum, or plasma taken at about 20 to 22 days after breeding are low in nonpregnant cows and elevated in pregnant cows. Most cows with low progesterone concentrations approximately 20 to 22 days after AI are not pregnant. Cows with low progesterone may be coming into estrus, may be in standing estrus, may be going out of estrus, may have a follicular ovarian cyst, or are anestrus. In contrast, cows with high progesterone at 20 to 22 days after breeding are assumed to be pregnant. Accuracy of diagnosing a cow as pregnant based on a high progesterone is approximately 75% (Zaied et al, 1979). Cows assumed to be pregnant early based on a high progesterone should always be confirmed pregnant by palpation or ultrasonography later in gestation, because other conditions such as AI of cows not in heat, inaccurate breeding records, early embryonic death, pyometra, and cystic ovaries can result in cows being diagnosed pregnant erroneously.

Milk progesterone assay is the most effective on-farm method to assess the accuracy of estrus detection (Nebel et al, 1987). Although a low progesterone level does not guarantee that the cow is in estrus or that insemination was performed correctly (and correctly timed relative to estrus and ovulation), a high progesterone level does indicate that the cow was *not* in estrus. We have found milk progesterone assays to be helpful when working up herds with low pregnancy rates and a suspected estrus detection problem. The dairy producer may collect and freeze milk samples from each cow at the time of breeding. After a suitable number of samples have been collected, they can be assayed for progesterone concentration. Results of progesterone assays allow the practitioner to determine the percentage of cows inseminated that were *not* in estrus (as indicated by a *high* progesterone concentration). The insemination of cows not in estrus can be a serious problem on both large and small dairy farms (Reimers et al, 1985; Slenning and Farver, 1990). In a study of dairy farms in the northeastern United States, Reimers et al (1985) found that 5% to as high as 60% of

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cows among herds were inseminated and not in heat based on high concentrations of milk progesterone. *The practitioner should be alerted to a potential estrus detection problem when more than 5% of cows that are called in heat and inseminated also have high progesterone in milk.* These assays may also be used to determine the percentage of heifers with high progesterone that may be responsive to PGF treatment for estrus synchronization, and for differentiating between luteal (high progesterone) and follicular (low progesterone) ovarian cysts in cows (Sprecher et al, 1988).

Cytogenetic Testing

Cytogenetic evaluation of individual animals is needed to confirm parentage or to provide the practitioner with additional diagnostic information for specific conditions such as freemartinism (Buoen et al, 1981). These tests can be performed by diagnostic laboratories on bovine lymphocytes or on tissue such as a skin biopsy.

Vaginoscopy

A clear plastic vaginal speculum allows for rapid examination of the vaginal vault for assessing trauma to the cervix and vagina following calving and for visualizing the external os of the cervix for detection of normal discharges (e.g., lochial discharges found early postpartum, or clear mucus discharges of estrus) and abnormal discharges (e.g., purulent endometritis).

Uterine Culture and Biopsy

Samples of uterine fluid for aerobic and anaerobic bacteriological evaluation may be indicated in cows with severe or chronic uterine infections. Sterile infusion pipettes that are guarded from contamination while passing them through the vaginal vault can be used to obtain fluid from the uterus or cervix of cows (Mortimer et al, 1997).

Biopsy of the endometrium of the cow has been used to provide histological evidence in the diagnosis of endometritis. However, biopsy of the endometrium may result in decreased reproductive performance of cows (Etherington et al, 1988); thus it is not recommended as a routine herd procedure.

Recovery of Embryos

Superovulation treatment followed by AI and uterine lavage (flush) may be used to recover embryos or oocytes from cows suspected of having problems associated with the uterine tubes or ovulation. Recovery of embryos or oocytes by uterine flush with a phosphate-buffered saline solution on Day 7 or 8 after insemination can help confirm ovulation and patency of the uterine tubes (Bowen et al, 1978).

ENHANCING REPRODUCTIVE EFFICIENCY

The goal of reproduction on a dairy farm is to produce a calf, thereby inducing a new lactation. Accomplishment of this goal depends on production of viable oocytes, delivery of these oocytes to the oviduct for fertilization, availability of viable spermatozoa in the the oviduct, transportation of the fertilized ovum to the uterus, successful signaling of maternal recognition of pregnancy, development of the placenta, physiological maintenance of the pregnancy, and successful parturition. Indeed, there are many physiological and pathological causes of reproductive failure in dairy cows. Fertilization failure and early embryonic mortality are major contributors to reproductive failure in cattle (Zavy, 1994). Factors that decrease fertilization rates include production of poor quality or aged oocytes, use of semen from low-fertility bulls, and poor timing of insemination relative to days postpartum or ovulation. In cows with no disease problem the rate of embryonic mortality is relatively stable although subject to decrease by poorly timed insemination or by such factors as high environmental temperature, use of semen from low-fertility bulls, and insemination of pregnant cows. Fertilization rate almost certainly can be improved, to a marked degree in some dairy herds, by inseminating only cows in estrus, correcting errors in semen handling, improving the timing of insemination relative to first observed standing estrus, and inseminating cows with semen from bulls of proven fertility.

Additional factors that are critical to high reproductive efficiency include management efforts to reduce nutritional and lactational stress in early lactation. The maintenance of appropriate energy balance and nutrient intake reduces the incidence of fatty liver, fat cow syndrome, and ketosis. Positive steps should also be taken to prevent the introduction of brucellosis, *Campylobacter* sp., leptospirosis, trichomoniasis, and other infectious causes of infertility as well as selection against bulls, and possibly cow families, that have a high incidence of dystocia. Culling policy also has an important effect on reproductive efficiency. For example, if all cows that do not exactly match reproductive targets are immediately culled, the apparent reproductive efficiency of the herd at any one time is considerably enhanced. The numbers may look good, but the total effect on the herd's economy may be disastrous because of the young average age of the herd and the almost certain result of a lowering of the herd's milk yield and increased costs for replacement heifers. Alternatively, if the culling policy is directed solely at improving cow milk production, there may be a tendency to keep old or infertile cows because of their genetic worth.

As discussed earlier in this chapter, milk production of cows has increased and reproductive performance of cows has declined during the past 20 years as evidenced by increased days open and decreased conception rates. Problems related to breeding management (e.g., elective postponement of rebreeding and low estrus detection rate) and the negative influences of high milk production and heat stress may be responsible for this decline in reproductive efficiency. This suboptimal level of reproductive performance in many dairy herds is matched by the paradox that, in some herds, substantially higher levels of performance are achieved. Dairy farms with successful reproductive programs incorporate excellent cow nutrition, a committed management team, effective estrus detection programs, strategic use of estrus synchronization protocols, attention to breeding techniques, and routine reproductive examination and treatment of problem cows. In general, efforts to improve reproductive performance of cows on individual farms have been shown to be profitable (Galton et al, 1977).

Postpartum Uterine Infections

Postpartum infection of the uterus has long been considered an important cause of bovine infertility (Erb et al, 1981a,b). Dystocia, twinning, and retained fetal membranes increase the risk of a cow developing postpartum uterine infections. Management efforts should be directed toward prevention of uterine infections by providing cows with adequate nutrition, maintaining sanitation in the calving area, and reducing the incidence of dystocia. Cows with certain types of uterine infection, such as cows with pyometra, usually respond very well to treatment with PGF alone. However, cows with other infections of the uterus such as severe metritis

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and chronic endometritis often require additional antibiotic therapy (Youngquist and Shore, 1997).

Postparturient Metabolic Diseases

Milk fever, ketosis, and other metabolic diseases may adversely affect reproductive performance of cows. These diseases may affect the oocyte by altering normal follicular development contributing to defective follicles that are recruited for ovulation during the optimum breeding interval. For example, acetonemia is reported to have prolonged the calving-to-conception interval of affected cows by 51 days and increased the services per conception rate by 0.73 services (Nenadovic et al, 1979).

Early Postpartum Estrous Cycles

Practices to encourage early postpartum estrous cycles and breeding after calving help to reduce the intercalving interval but often at the expense of lower conception rates. However, this practice does not appear to have any apparent deleterious effect on long-term fertility (Williamson, 1980). The simple monitoring of reproductive status, especially postpartum estrous cycles, does not encourage greater reproductive efficiency of itself (Munro et al, 1982). There must be intervention by the producer and the veterinarian so that the recognition of an impending problem is countered by preventive actions. In particular, adjusting the ration to provide an adequate dry matter intake and a nutritional level to meet the needs of early lactation and conception is a common strategy. Cows should be fed during the dry period and early lactation to minimize the negative energy balance that is detrimental to the return of cyclicity. The feeding program should avoid excessive weight gain in dry cows but should be a high-energy density ration after calving. The relationship between fertility and roughage, rather than concentrates, has been demonstrated (Bogin et al, 1982). High-quality forages should be fed to, and attention paid to the neutral detergent fiber (NDF) and dry matter intake of, cows in the first several weeks' postpartum.

There is convincing evidence that the fertility of cows is significantly affected by their energy and health status 2 to 3 months before the estrous cycle of breeding. Cows in significant negative energy balance sustain damage to the developing population of follicles that are recruited for ovulation 2 to 3 months later. This contention is supported by several observations. Cows in hot climates have reduced fertility for up to 2 months after high temperatures have passed (Faust et al, 1988). Early postpartum clinical disorders can affect fertility 60 to 80 days later, despite the fact that the primary disorder has long since healed (Oltenacu et al, 1983). Negative energy balance in the first 9 days postpartum reduces progesterone levels of cows during the luteal phase of their second and third postpartum estrous cycles (Villa-Godoy et al, 1988). Cows that lose a significant amount of weight (more than 0.5 body score points, 5-point scale) in early postpartum have extended days to each ovulation and have significantly reduced conception rates for at least the first three services (Britt, 1991). This difference is not simply a function of milk production. The difference in reproductive performance was seen even though the groups that did not lose as much weight on average gave the same amount of milk as the group that lost weight. In another study, cows that lost 1 body score point had a first-service conception rate of only 17% compared with conception rates over 50% for cows that lost less than 1 body score point (Butler and Smith, 1989).

Another nutritional aspect that appears to influence reproductive function is the amount and character of the protein in the cow's ration at the time of insemination. Cows fed high levels of rumen-degradable protein have been shown to have reduced reproductive efficiency (Ferguson and Chalupa, 1989). Similarly, heavy feeding during the dry and peripartum periods alter follicular development and decrease reproductive performance. Nutritional deficiencies that lead to the loss of body condition, as well as deficiencies of copper, cobalt, iodine, iron, and selenium, may also reduce reproductive efficiency indirectly (see Chapter 11).

The most favored biological treatment to restore estrus cycling after parturition is the maintenance of good condition during the dry period, at calving, and during early lactation. Efforts have also been made, however, to modulate the return to fertile estrus by the use of hormone therapy in the early postpartum cow. Variable results have been observed when PGF or gonadotropin-releasing hormone (GnRH) was used in dairy cows during the postpartum period, as measured by the impact on subsequent fertility and days open (Etherington, 1984; Etherington et al, 1988; Oxender, 1991). In regards to the effect of administration of these hormones on subsequent uterine infection, the use of GnRH during the postpartum period may increase the incidence of pyometra (Etherington, 1984). However, the use of PGF during the postpartum period may decrease the occurrence of pyometra (Etherington et al, 1988).

Detection of Estrus

Inaccurate estrus detection can lead to incorrect timing of insemination and insemination of cows that are not in estrus. Ideally, cows should be inseminated about 12 hours after first observed estrus (AM/PM Rule). The detection of behavioral estrus in cows must be a planned activity on the farm; just like milking is a planned activity. Observation of the herd for 30 minutes in the morning before and after milking, at midday, and late in the evening allows the accurate detection of estrus, but few producers take the time to do the task properly. In herds in which cows have access to pasture or exercise lots, tail chalk, pedometer, and heat mount detectors as well as the use of cows treated with testosterone (androgenized cows) are possible alternatives. Although each method is successful and preferred in a particular environment (Fulkerson et al, 1983), tail chalk or tail paint is preferred in most cases because of low cost and ease of application. A thick layer of chalk is applied to the hair and skin over the dorsal spines of the sacral and first coccygeal vertebrae. The chalk is rubbed off when a cow stands in response to being mounted by other cows. Surgical preparation of bulls to be used as heat detectors on dairies has serious disadvantages, including vaginal entry of cows and the possible introduction of venereal disease.

Progesterone concentrations of milk or serum may be used to monitor estrus detection accuracy (see "Progesterone Assays" section for details). Inaccurate estrus detection can appear as decreased conception or pregnancy rates and should be considered before focusing on areas such as inseminator error, semen quality, or cow infertility.

Another approach for evaluating estrus detection accuracy is to examine the intervals between one estrus event and the next. If estrus detection is accurate, the interestrus interval should be either 18 to 24 days or 38 to 45 days, and at least 60% of second estrus events should be in these intervals (Weaver and Goodger, 1987a,b). If the interval is not, the presumption is that at least one of the two cycles was detected incorrectly. However, *interestrus intervals are of little value in herds in which prostaglandins are used regularly to synchronize estrus.* This measurement is also confounded by extended estrous cycle length associated with early embryonic death. In addition, for estrus events two cycles from the first,

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the variability of the timing of the second cycle is such that it can be difficult to be confident which estrus is within the appropriate window of time.

Inseminator Efficiency

The person doing the AI can have an important effect on herd fertility. Poor technique in storage or in thawing straws of semen as well as failure to deposit the semen in the uterine body can reduce fertility. The veterinarian should work to assess and monitor the effectiveness of the farm's inseminators by observation and analysis of breeding results. In small dairy herds, the practitioner must be careful not to overinterpret the results of a limited number of breedings.

Examination of the Reproductive System and Records

Regular visits by a veterinarian to examine cows for evidence of pregnancy and to uncover reasons for nonpregnancy are the basis for reproductive herd health programs. These visits also provide an ideal opportunity to review reproductive records of cows and discuss targets for the farm's reproductive and breeding program. The frequency of herd visits depends on herd size, season, and the specific goals of the farm's reproductive program. Farm visits are often conducted monthly or biweekly on small- to medium-size dairies and weekly on large dairy farms.

Control of Reproductive Diseases

Control measures for infectious diseases causing reproductive failure in dairy cows vary depending on the prevalence of the disease and the specific location of the dairy farm. Infection and abortion caused by bovine brucellosis has decreased in many parts of the world. In contrast, leptospirosis is still a serious cause of bovine abortion in many areas and is controlled by vaccination two or more times with a multivalent bacterin and by reduction of exposure of cows to potentially contaminated materials on the farm such as polluted water or aborted fetuses. Infection with *Campylobacter fetus* ssp. *venerealis* (formerly *Vibrio fetus*) in dairy cattle is controlled by AI. Where natural breeding is practiced, vaccination of the bull before the breeding period may be an effective method to control the spread of this venereal disease. Trichomoniasis is rarely seen in dairies and is effectively controlled by the use of AI. Bovine abortions caused by herpesvirus or infectious bovine rhinotracheitis (IBR) are controlled by vaccination. Abortions caused by bovine virus diarrhea (BVD) are also controlled by vaccination as well as by detecting and eliminating contact with infected animals (Barr and Anderson, 1993).

Estrus Synchronization Programs

Failure to detect estrus and inaccurate estrus detection are the major reasons for poor reproductive performance on many dairies. Low estrus detection rates have stimulated an increased interest among producers in effective programs for synchronization of estrus and ovulation in cows. Improvements in reproductive performance of groups of cows in heat at one time can be attributed to an increased opportunity to detect cows in standing heat or to inseminate groups of cows at a fixed-time regardless of standing heat. These programs also concentrate labor efforts in the breeding program. Ideally, estrus synchronization protocols should control the function of the CL, the development of ovarian follicles, and the ovulation of follicles with viable oocytes. A variety of different synchronization protocols have been used successfully in dairy cows, and new protocols are developed continually to improve rates of synchronization of estrus and ovulation as well as rates of conception following AI. This section discusses commonly used synchronization programs for cows and heifers (for review, see Whisnant et al, 2000).

Essential prerequisites for a successful estrus synchronization program are excellent cow and heifer management including identification (readable ear tags) as well as maintenance of records of all animals to be synchronized, detected in estrus, and inseminated. Success of synchronization programs in dairy cattle may be measured by rates of estrus detection, conception, and pregnancy.

Synchronization programs use special terms to describe outcomes. Estrus detection rate refers to the percentage of cows detected in standing heat among those cows eligible to be detected in heat. *Conception rate* represents the percentage of cows that became pregnant among those cows actually inseminated. *Pregnancy rate* refers to the percentage of all eligible cows that are diagnosed pregnant during one estrous cycle or synchronized breeding period. Thus pregnancy rate is influenced by heat detection efficiency and by both conception rate and estrus detection rate. Conception rate and pregnancy rate are synonymous for protocols that use fixed-time insemination of all cows or heifers.

Prostaglandin and Analogs

Protocols incorporating prostaglandin $F_{2\alpha}$ (PGF) or its analogs are commonly used in cows and heifers to induce a synchronized estrus by shortening the length of the estrous cycle. Recall that a functional CL is necessary for PGF to be an effective synchronization treatment because PGF acts by causing lysis of the CL. A standard protocol is to administer two injections of PGF 14 days apart. This 14-day treatment protocol is easy for producers and practitioners to schedule. Cows responding to treatment will exhibit standing heat 1 to 5 days after the second injection of PGF, and they can be inseminated at the usual time relative to standing heat or at a fixed time after the second injection of PGF. Although different intervals between injections of PGF may be used to synchronize estrus, subsequent cycle length and pregnancy rate may be influenced by the interval between injections of PGF. For example, pregnancy rates were greater for cows receiving PGF injections 14 days apart compared with those that received injections only 11 days apart (Folman et al 1990).

Timed insemination following PGF injection has been attempted; however, in most studies conception rates have been consistently lower than insemination after detection of treatment with PGF (Stevenson et al, 1987; Archbald et al 1992). For example, Stevenson et al (1987) found a 23% conception rate after a single AI at 80 hours after PGF treatment compared with 54% for AI at 12 hours after detected estrus. In that study the use of two inseminations at 72 and 96 hours after treatment with PGF produced conception rates of 30%. It is likely that lower fertility following timed insemination can be attributed to differences in follicular wave development at the time of CL regression, causing varying times to estrus and ovulation (Thatcher et al, 1996).

Results of economic models of estrus control on dairy farms have shown that the practice of using prostaglandins on dairies is usually profitable (Fetrow and Blanchard 1987). However, this is not likely true when these programs are based primarily on detection of the CL before administration of PGF (Ferry, 1992). This is likely due to the limited accuracy of palpation alone for identifying CL (Kelton, 1991). Several researchers have attempted to identify cows that should respond to PGF based on elevated progesterone

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concentrations in milk. Stevenson and Pursley (1994) compared PGF treatment of cows with high milk progesterone concentrations to cows submitted for insemination based on detection of standing estrus. The use of milk progesterone tests decreased days to first AI, calving intervals, and cost per pregnancy; however, the cost was greater than weekly injections of PGF to all noninseminated animals. In another study, Kristula et al (1992) found that weekly PGF injections followed by standard estrus detection decreased days to first insemination and increased pregnancy rate by 30% over the first 90 days postpartum compared with PGF treatment of cows identified as having a CL by palpation *per rectum*. In addition, the costs per pregnancy were also less for the weekly PGF injection program.

Heifers that have attained the appropriate age and weight for their breed to begin normal estrous cycles may also be synchronized using PGF at a 10- to 12-day interval.

Gonadotropin-Releasing Hormone and Prostaglandins

Protocols for synchronization of estrus as well as control of follicular waves and ovulation have now become an integral part of reproductive management programs for lactating cows on many dairies. These protocols are based on the findings that treatment of cows with GnRH or an analog could induce ovulation or luteinization of dominant follicles (Twagiramungu et al, 1995). The addition of a second injection of GnRH after PGF has allowed for the use of timed insemination (insemination following hormone treatment without estrus detection) in lactating cows (Pursley et al, 1995; Stevenson et al, 1996). A commonly used protocol in lactating cows consists of GnRH (100 μg), followed 7 days later by PGF (25 mg Lutalyse), then 48 hours later by a second injection of GnRH, then AI of all cows 16 hours later (Ovsynch protocol). Cows between days 5 and 12 of the estrous cycle respond best to the Ovsynch protocol. This protocol is effective in lactating cows but not in heifers, perhaps because of differences in follicle waves between cows and heifers (Pursley et al, 1997a,b).

Because fixed-time insemination protocols do not involve estrus detection, they offer significant advantages to dairy producers. However, to be efficacious, conception rates for these programs should be similar to those seen for AI after estrus detection. In a recent review, Whisnant et al (2000) compared the results of seven different studies in which cows were given either a standard 14-day PGF treatment and AI after detected estrus or an Ovsynch with fixed time insemination. Conception rates, although variable, tended to be slightly less with Ovsynch; however, pregnancy rates were generally higher with Ovsynch than after PGF treatment, with estrus detection rates often being the determining factor. Across the seven studies, conception rates ranged from 22% to 47% for the PGF treatment and from 27% to 47% for Ovsynch. Pregnancy rates ranged from 11% to 30% for PGF treatment and from 27% to 47% for Ovsynch. For example, Pursley et al (1997a,b) compared the Ovsynch protocol with regular PGF injections followed by estrus detection. Pregnancy was diagnosed using ultrasonography at 32 to 38 days after insemination. Animals found not pregnant were started again on the same protocol used previously. First service pregnancy rates were similar for both groups of cows (37% for Ovsynch and 39% for PGF treatment), but days to first service and days open were decreased for the Ovsynch protocol. Pregnancy rates by 60 and 100 days were greater for cows that received Ovsynch (Pursley et al, 1997b). Britt and Gaska (1998) evaluated the Ovsynch method and two injections of PGF 14 days apart, and found no differences between the two treatment groups in conception rates, but pregnancy rates were increased and services per conception decreased in the Ovsynch group. Based on costs of a $1 (U.S.) per day cost for days open and $10 for labor, the Ovsynch program was significantly less expensive than the PGF method (Britt and Gaska, 1998). The cost of the Ovsynch protocol may be lowered by using half the dose of GnRH (50 μg) without adversely effecting pregnancy rates (Fricke et al, 1998).

About 60% or more of cows will not conceive the first time with these protocols and must be dealt with subsequently. It appears that pregnancy diagnosis with ultrasonography may be an effective method for early identification and retreatment of these open cows. In one study, Moreira et al (1997) examined resynchronization of cows that have gone through the Ovsynch protocol. Cows in that study were given GnRH on Day 20 after AI and examined for pregnancy using ultrasound on Day 27 after AI. Open cows were given PGF at this time and were inseminated after estrus or given GnRH 48 hours later and bred 16 hours after GnRH. Pregnancy rate after the ultrasound examination for the resynchronized cows was 33%, which was similar to pregnancy rates after the first insemination.

Progesterone and Analogs

Progesterone or its analogs can be used to synchronize estrus in cows. Although this method has not yet been approved for use in lactating dairy cows in the United States, research on its use has been conducted and is approved in other countries. Two devices have been developed for cattle: a progesterone-releasing intravaginal device (PRID) and a controlled internal drug-releasing (CIDR) device. The CIDR contains progesterone in a silastic elastomer and a capsule containing estradiol benzoate, and the PRID consists of progesterone in a silicone elastomer coil with estradiol benzoate in a gelatin capsule. The degree of synchrony increases with the length of time the CIDR is in the cow, but pregnancy rates decrease with increased length of progesterone treatment (Macmillan and Peterson, 1993). Prostaglandins or estradiol may be used after the removal of a progesterone-releasing device (Xu et al, 1997).

Embryo Transfer and Related Biotechnologies

Embryo Transfer

The dairy industry has used AI extensively to improve herd genetics by exploiting intensive selection applied to sires and dams of AI bulls. Dairy producers are also the primary users of embryo transfer (ET). ET allows for the production of more offspring from a cow in a shorter period, effectively decreasing the generation interval. In addition, frozen embryos may be transported nationally or internationally and may be used in the control of transmission of certain diseases (Stringfellow and Seidel, 1998). The scope of ET has expanded tremendously in the past 10 years. Today conventional ET may also be linked to other reproductive biotechnologies such as embryo sexing, semen sexing, oocyte collection, and in vitro embryo production (IVP) as well as the more recent applications to transgenesis, cloning, and marker-assisted selection for specific disease resistance and production traits (Bishop et al, 1995).

Animal-breeding models of the impact of superovulation and conventional embryo transfer (Multiple Ovulation and Embryo Transfer [MOET]) of superior dams have shown that these breeding systems were of value for developing elite populations of dairy cattle for progeny testing (Nicholas and Smith, 1983). Further acceleration of genetic gains may be possible by including links to other biotechnologies, such as IVP, in these breeding systems (Dekkers, 1992). However,

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the potential economic benefits of using ET vary between producers but should be most evident when based on the sale of calves resulting from ET (Everett, 1984).

Superovulation treatment of the embryo donor cow as well as AI, embryo collection, and transfer are typically performed on the farm or at an ET facility. Briefly, multiple ovulations are commonly induced in donor cows and heifers by administration of follicle-stimulating hormone (FSH) during the midluteal phase of the estrous cycle and PGF or an analog at the end of FSH treatment to induce estrus. Donors are then artificially inseminated based on standing estrus, and embryos are collected nonsurgically by uterine lavage (flush) on Day 6, 7, or 8 after estrus. Total number of embryos recovered per donor is variable; however, most donor cows will average four to six transferable-quality morulae or blastocysts per flush (Hahn, 1992; Hasler et al, 1983). Variation is present both within and between donors in superovulatory response to FSH treatment, total number of embryos recovered, and the proportion of transferable quality embryos. Variability in number of recovered embryos has been attributed to environmental effects such as farm (Hahn, 1992).

Recovered embryos are either transferred nonsurgically into recipients on Day 7 (±1 day) of their estrous cycle or frozen and stored in liquid nitrogen for future transfer with good results (Hasler et al, 1987). Recent developments in cryopreservation techniques have led to successful freezing of embryos in ethylene glycol, the rapid thaw of embryos in a warm water bath, and the transfer of embryos directly into recipients (called "direct transfer" [DT]). Embryos intended for DT are packaged and frozen in yellow straws. It is important for practitioners to follow the guidelines established by the International Embryo Transfer Society when collecting and processing embryos for commercial purposes (Stringfellow and Seidel, 1998).

In vitro Production of Embryos

IVP refers to the use of laboratory systems to produce embryos. This process usually includes retrieval of oocytes from the ovaries of a cow, in vitro maturation of oocytes, in vitro fertilization, and in vitro culture of presumptive zygotes to the blastocyst stage of embryo development. Birth of the first calf resulting from the transfer of an embryo that had undergone in vitro fertilization and culture was reported by Brackett et al in 1982. Embryos are now routinely produced in laboratories worldwide through the use of a variety of culture systems. Applications of IVP in cattle include production of embryos from either nonpregnant or pregnant cows for transfer into recipient heifers; genetic salvage of donor cows, production of embryos from cows that respond poorly to superovulation treatment, or cows with acquired blockage of the uterine tubes. Furthermore, IVP may be used in the production of potential AI sires, production of half-sib embryos using semen from different sires, and production of embryos for transgenesis, cloning, and related research. Producers often alternate between IVP and conventional ET in an attempt to increase embryo production from donor cows. IVP services are available to dairy producers at several embryo transfer facilities and universities.

Briefly, oocytes may be harvested from ovarian follicles using ultrasound-guided transvaginal oocyte retrieval (TVOR). Oocyte retrieval may be repeated frequently either on the farm or at an ET facility until the desired number of oocytes are obtained. The yield of transferable quality embryos after IVP varies from about 25% to 35% or greater. Acceptable pregnancy rates can be achieved after transfer of IVP embryos; however, these rates are usually lower than those seen after transfer of embryos from conventional superovulation and ET (Hasler et al, 1995). Calves resulting from the transfer of embryos produced in vitro may have increased birth weight and placental problems such as an increased incidence of hydrallantois (called "Large Offspring Syndrome") (Hasler et al, 1995; van Wagtendonk-de Leeuw et al, 2000). Thus recipients carrying pregnancies from the transfer of IVP embryos may require obstetrical assistance at the time of parturition.

Sexed Sperm and Sexed Embryos

Successful use of sexed spermatozoa has been demonstrated in a variety of species, including the bovine (Seidel and Johnson, 1999). Sex ratios of approximately 90% heifer or bull calves are possible after insemination of heifers with sexed sperm (Seidel et al, 1999). The use of sexed sperm may allow dairy producers to target part of their breeding programs for production of replacement heifers, or perhaps production of bull calves for potential AI sires. Sexed sperm cells may also be used in IVP systems to produce embryos of a predetermined sex for transfer. Spermatozoa are sexed based on differences in their X-Y DNA content. Recent improvements in high-speed sorting of spermatozoa indicate that sexed semen will likely become available for commercial on farm use in the near future.

In contrast to the potential future use of sexed sperm, the transfer of embryos of a predetermined sex has already been used by dairy producers for several years. The method for sexing embryos involves biopsy of the embryo mass and determining genetic sex using rapid PCR techniques. A simplified method of embryo biopsy and sex determination allows embryos to be sexed before ET on the farm (Bredbacka et al, 1995).

Transgenesis and Nuclear Transfer

In the future, nuclear transfer and transgenics may influence the dairy industry and the dairy producers' breeding program. Transgenic biotechnology is used to make animals with a gene or genes that are not their own. In contrast, cloning by nuclear transfer allows for the production of a series of genetically identical individuals. The potential economic returns for producing transgenic dairy animals for pharmaceutical and food purposes have fueled research efforts in these areas. Potential future applications of transgenics and nuclear transfer in dairy cattle include modifying genes for important production traits such as the polled trait, heat resistance, and disease resistance; enhancing the nutrient value of milk; changing milk components for more efficient processing and digestion of dairy products; and producing biopharmaceutical products such as clotting factors, anticoagulants, and blood replacement products (Bishop et al, 1995; Wall, 1996).

INVESTIGATING REPRODUCTIVE INEFFICIENCY

General Procedure

An investigation of decreased reproductive inefficiency in dairy cows includes a clear definition of the problem, examination of the cases, and formulation of a plan of action. A guide for conducting an examination of a herd for a reproductive problem is shown in Table 7-3. In addition, different causes of reproductive failure are shown in Table 7-4, and the common causes of abortion in dairy cows are outlined in Table 7-5. The relative importance of each of these causes varies widely from farm to farm and even from time to time on any one farm. An accurate diagnosis of reproductive failure is, to a large extent, dependent on how much importance

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TABLE 7-3

General Approach to Reproductive Problems on a Dairy Farm

Action	Information Source/Comments
Describe the problem	Records analysis and history; animals affected (individuals, group, or herd; parity; days in milk; etc.)
Prevalence	Season of year; specific location on farm (e.g., calving lot, milking lot, pasture)
Pattern	Category of problem: "cow fertility," "bull fertility," "breeding management," or "environment"
Cost to farm	See text and Tables 7-4 and 7-5
Investigate cases	Physical examinations
	Evaluate breeding management and cow management
	Diagnostic tests as needed
	See text and Tables 7-4 and 7-5
Formulate a plan of action	Treatment of cases/herd; changes in cow management, breeding practices, or facilities as indicated
Intervention	Follow-up exams/diagnostic tests
Prevention	Change plan of action as indicated
Monitor response	See text sections "Reproductive Parameters for Measuring Success" and "Monitoring Reproductive Performance" and Tables 7-4 and 7-5

the producer and veterinarian place on the reproductive program of the farm. This section presents a summary of the more common causes of reproductive failure in dairy cattle.

In herds on a computerized herd health program, a decline in reproductive performance becomes obvious early if the responsible veterinarian is paying close attention to the reproductive indexes produced at monthly intervals by the program. In other herds the problem is often much further advanced at the time it is recognized. It is a great advantage in these herds (if they have sufficiently good data) to begin the investigation by analyzing their records. Thoughtful examination of the records can often narrow the likely problem area. This can make the on-farm part of the investigation much faster and more effective. Indeed, the practitioner challenged with solving a reproductive problem will appreciate that these problems are often closely linked to one another. For example, cows with twins are more likely to suffer dystocia and have retained fetal membranes. In addition, cows with metabolic disorders such as ketosis as well as dystocia and retained placenta have increased risk of developing metritis (Correa et al, 1993). In general, reproductive problems in dairy cattle are often noninfectious, temporary conditions. However, *the practitioner should always rule out infectious causes first when investigating cases of abortion.*

The workup of reproductive inefficiency should begin with a systematic analysis of available records on the affected group of animals within the herd. This allows the clinician to determine the prevalence and pattern of the problem as well as the relative cost of the problem to the farm. The more cows available for analysis of pregnancy data, the better the estimates of herd fertility. Reproductive inefficiency often affects cows in a particular lot or parity such as a nutrition problem, or it may be scattered throughout the herd and associated with a point-source such as a poor semen handling or insemination by a particular AI technician. Alternatively, reproductive problems can appear as one or more nonpregnant individual animals that an owner has a keen interest in getting bred.

Specific on-farm investigations are different depending on the major problem area(s). However, by gaining a broad view of the farm's problems through records analysis, problem areas that have not come to the farmer's attention are not overlooked. For example, a herd that is having a problem with anestrous cows often also has a problem of repeat breeders or early postpartum disease. Regardless of the problem, it is usually productive to obtain a general history about breeding practices, artificial or natural breeding, timing of breeding, techniques used, method of estrus detection, status of nutrition and BCSs, disease control programs, and introduction of new animals. At the point at which individual cow information is needed, the use of a combination of each cow's reproductive record for the past year and the findings on physical examination of the genital tract makes it possible to define the cow's reproductive status. It is much easier to do this if the breeding history of the herd has been submitted beforehand, the cows' records evaluated, and a comprehensive list of cows to examine has been produced. This indicates those cows that need examination and outlines their immediate past histories and the reasons for selecting them for examination.

Overall reproductive performance (days open, abortion rate, culling rate, disease rates) should be examined. If excess days open is the major problem, then the next step is to break the days open into potential sources. Assuming an acceptable voluntary wait period and no excess pregnancy wastage, excess days open can be attributed to poor conception, poor estrus detection, or both (see the "Tools to Expand the Value of Standard DHIA-Based Reproductive Indexes" section later in this chapter). Conception problems can be further segmented by looking at conception rates for various subgroups of cows (e.g., all cows, pregnant cows, heifers). If conception rates in pregnant cows are high, attention can be directed at estrus detection accuracy, insemination and semen quality, and problems affecting the herd as a whole, such as malnutrition or high environmental temperatures. If conception rates in pregnant cows are acceptable, then causes affecting specific subgroups of cows can be addressed (e.g., postpartum disease, infectious disease in younger animals).

Estrus detection problems usually lead the investigation directly to the farm to consider management and labor, housing, nutrition, and foot and leg problems. If estrus detection accuracy problems are suspected, the dairy producer can be asked to collect milk from cows at breeding to determine milk progesterone levels. In contrast, abortion problems require both on-farm and laboratory investigations, as do most

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TABLE 7-4

Diagnosis of Problems Associated with Reduced Fertility in Dairy Cattle

Category of Fertility Problem	Relative Frequency of Occurrence	Method of Diagnosis/Comments
COW FERTILITY		
Early embryonic death	High	Early pregnancy diagnosis using ultrasonography; interestrus intervals >18-24 days often difficult to determine in herds using estrus synchronization programs
Abortion	Varies	See Table 7-5 for differentials and methods of diagnosis
Dystocia	Varies	History; vaginal-vulvar lacerations; check age at calving, herd goal: <10%
Other accidents of gestation	Low	Reproductive examination, history; examples: hydropsical conditions of placenta or fetus, fetal mummification, fetal maceration
Uterine infection	Varies	Reproductive examination, bacterial culture; includes metritis, pyometra, and endometritis; often a sequela to dystocia or retained fetal membranes; herd goal: <10%
Vulvitis and vaginitis	Varies	Reproductive examination, vaginoscopy, microbial culture; infectious conditions include granular vulvitis, and infectious pustular vulvovaginitis
Urovagina; pneumovagina	Low	Reproductive examination; sequela to dystocia, obstetrics, trauma, or poor perineal conformation
Inflammation and adhesions of cervix, oviducts, ovaries	Varies	Reproductive examination; recovery of embryos to check oviduct patency; sequela to dystocia, trauma, or uterine infection; common conditions include: cervicitis, salpingitis, and occasionally ovaritis
Ovarian cysts	Varies	Reproductive examination; most cows with ovarian cysts are anestrus; herd goal: <10%
True anestrus	Low	Reproductive examination; ration analysis
Metabolic disease	Varies	Physical examination, urine or serum biochemistry, ration analysis
Freemartinism	High	Heifers born co-twin to a bull; physical examination and/or cytogenetic testing of suspected heifer
Segmental aplasia	Rare	Reproductive exam, necropsy; examples: white heifer disease, uterus unicornis; congenital/heritable
Ovarian hypoplasia	Rare	
Ovarian tumors	Rare	History, palpation/ultrasonography; histopathology for definitive diagnosis; granulosa cell tumor is most common
BULL FERTILITY		
Poor semen quality	Varies	Rule out problems with estrus detection, semen handling/AI technique first; check liquid nitrogen tank, individual straws for semen quality, contact AI center, use high fertility AI sire; breeding soundness examination of herd bull
Poor libido and/or serving capacity	Low	Observe herd bull service cows; aggressive behavior may interfere with mating activity
Reproductive diseases of herd bulls	Varies	Campylobacteriosis and trichomoniasis; encourage the use of AI
Developmental abnormalities of bulls	Low	Examples include central fusion of chromosomes and chimerism
Sire influence on size of calf	High	Check calving ease scores of AI sires in herds with increased dystocia
BREEDING MANAGEMENT		
Poor estrus detection	High	Palpation/ultrasonography or records indicate an increased percentage of nonpregnant cows; open cows with a corpus luteum on the ovaries should also have elevated milk progesterone levels (cycling); use milk progesterone at time of insemination to detect cows *not* in estrus at breeding; records analysis may reveal interestrus intervals >18-24 days; consider using estrus detection aids and estrus synchronization programs
Poor semen handling; AI technique	High	Check timing of AI relative to standing heat, placement of semen, temperature of semen thaw bath, level of liquid nitrogen in semen tank; consider an on-farm AI training session
ENVIRONMENT		
Heat stress	High	High ambient temperature is antagonistic to embryonic survival, and detection of cows in estrus
Inadequate facilities/ housing/footing	High	Poor footing; cows are more difficult to detect in estrus; high percentage of lame cows
Improperly balanced ration	Moderate	Ration analysis; body condition score
Toxic agents/ poisonous plants	Low-moderate	Consider high levels of nitrates (>0.20% of dry matter), zearalenone and other mycotoxins

AI, Artificial insemination.

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TABLE 7-5

Diagnosis of Bovine Infectious Abortion Diseases

Disease	Clinical Signs	Age at Abortion/ Fetal Loss	Fetal/Placenta Gross Lesions	Diagnostic Tests Available*	Test Samples*
VIRAL					
Infectious bovine rhinotracheitis	Abortion storm possible. No signs in aborting cows. Any form of clinical disease may be seen in herd on initial exposure.	Any gestational age; most in second half of gestation.	Fetus: none, autolyzed Placenta: possible edema.	Viral isolation . Fluorescent antibody. Immunohistochemistry. Histopathology.	Organ pool Kidney, lung, liver, adrenal, spleen, placenta. Same. Same.
				Abortion Dx requires infection + pathology	
Bovine virus diarrhea virus	Usually no clinical signs; however, any form of clinical disease possible.	Abortions usually in first 4 months. Live calves infected in utero may have cleared virus and be normal or have anomalies or persistent viral infections.	Abortions: none; possible mummies. Calves: None or deformities (cerebellar hypoplasia, hydrocephalus, ocular deformities, alopecia, thymic hypoplasia).	Viral isolation. Fluorescent antibody. Immunohistochemistry. Fetal antibody titer. Gross pathology. Histopathology.	Kidney, lung, spleen. Kidney, lung, spleen. Kidney, lung, spleen. Pleural fluid serum. Congenital deformities. Major organs, brain, eye (presumptive w/o detection).
BACTERIAL					
Leptospirosis	Infertility, abortions. Abortion storms possible. No signs in aborting cows. Acute fatal disease in young: icterus, hemoglobinuria. Agalactia, mastitis possible.	Abortion at any gestational age; placenta retained.	Fetus usually autolyzed with no gross lesions.	Fluorescent antibody. Serology. Bacterial isolation.	Kidney. Maternal pleural fluid: possibly specific titer. Difficult/impractical: kidney, urine, aqueous, humor, fetal fluids.
Campylobacter fetus ss. *venerealis*	Bull breeding operation. Infertility/early embryonic death. Some cows with metritis, sporadic abortions.	Abortions primarily between 4-7 months gestation.	Fetuses fresh, autolyzed or mummified. Possibly fibrinous pleuritis, peritonitis, pericarditis. Placenta thickened with surface exudate.	Bacterial isolation. Dark field microscopy. Histopathology.	Preputial smegma, vaginal secretions, placenta, fetal abomasal fluid, lung. Fetal abomasal fluid. Presumptive diagnosis: placenta, lung, liver.
				Limited value: Fluorescent antibody. Vaginal mucous agglutination.	Preputial/vaginal fluids. Vaginal secretion.
Brucellosis	No signs other than abortion.	Abortions in third trimester. Placenta retained.	Placenta thickened with surface exudate. Cotyledons mottled. Fetuses are usually fresh. Fetal bronchopneumonia.	Bacterial isolation. Serology.	Placenta, fetal abomasal fluid, lung. Uterus, milk, maternal lymph nodes. Maternal serum: see text. Fetal pleural fluid: possibly specific titer. Milk ring test.

From Barr BC, Anderson ML: Infectious diseases causing bovine abortion and fetal loss: infertility due to abnormalities of the ovaries in cattle. In Braun WF, Jr, Youngquist RS, editors: *Female bovine infertility*, Philadelphia, 1993, WB Saunders.

Kett. Potassium hydroxide.

*Suggested diagnostic tests and samples reflect the views of the authors and are based on submissions to the California Veterinary Diagnostic Laboratory System. Optimum samples and tests may vary at other laboratories.

Continued

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TABLE 7-5

Diagnosis of Bovine Infectious Abortion Diseases—cont'd

Disease	Clinical Signs	Age at Abortion/ Fetal Loss	Fetal/Placenta Gross Lesions	Diagnostic Tests Available*	Test Samples*
BACTERIAL (cont'd)					
Brucellosis				Histopathology.	Supportive: placenta, major organs.
Opportunistic bacteria	Usually no signs. Sporadic abortions. Possible abortion storms with *Salmonella* and *Listeria*.	Abortions at any stage, but most in last half of gestation.	Primarily placentitis and broncho-pneumonia. *Salmonella* and *Listeria*: fetus autolyzed.	Bacterial isolation. Histopathology.	Placenta, fetal abomasal fluid, lung, liver. Supports bacterial infection: placenta, major organs.
PARASITIC					
Trichomoniasis	Similar to *C. fetus ss. venerealis*. Primarily infertility, rare abortions.	Abortions primarily in the first 5 months of gestation.	Fetuses are autolyzed with no gross lesions. Placenta possibly edematous.	Protozoal isolation. Direct wet mount examination. Histopathology.	Preputial smegma, cervical mucus. Preputial smegma, cervical mucus. Placenta, fetal lung.
Neospora sp.	Abortion storms possible. No clinical signs in cows.	Abortions at any stage; most occur between 5-7 months gestation.	Fetuses are autolyzed with no gross lesions.	Histopathology. Immunohisto-chemistry.	Presumptive diagnosis: major organs, brain, muscle. Brain, primarily.
MISCELLANEOUS DISEASES					
Mycotic	Sporadic abortions. No clinical signs in cows.	Abortion usually in third trimester. Placenta may be retained.	Fetuses are usually fresh. Possibly focal dermatitis. Marked placentitis with leathery scarred foci. Possible fetal broncho-pneumonia.	Fungal isolation. KOH wet mount. Histopathology.	Placental or fetal lesions, fetal abomasal fluid. Skin lesions. Placenta, fetal skin, lung.
Epizootic bovine abortion	Abortion storms possible. Abortion in heifers and new cows. Limited to Southwest (tick vector). No clinical signs in cows.	Abortion usually in third trimester. Occasionally live, weak calves.	Fetuses are fresh. Enlarged lymph nodes, liver, spleen. Possible fibrin in body cavities, petechia in thymus.	Histopathology.	Major organs, thymus, lymph node, brain.

cases of excess clinical reproductive disease. Excess culling for reproductive reasons is usually best approached by first examining the individual records of cows culled for reproduction to determine the underlying problems in those cows.

Once the prevalence, pattern, and estimated cost of the problem are determined, individual cows or heifers should be examined with particular attention to the reproductive system and collection of appropriate samples for additional diagnostic testing. The practitioner then should outline and follow a plan of action for intervention, which should include the steps needed to resolve and prevent the problem in the future. Finally, the practitioner needs to devise a plan to monitor the problem and make additional changes in the plan as needed (Table 7-3).

Common Problems

The step of passing from classifying the type of infertility to the specific cause requires some knowledge of the relative frequency of the common causes. This ensures that, when an investigation is undertaken to determine the cause, the most likely one is not left until the end of the investigation before it is considered. The most common causes of reproductive inefficiency are, in order of descending frequency:

1. Inadequate estrus detection. As herds have increased in size and labor input per cow has been reduced, the management of details often declines. Detection of estrus is the most sensitive activity in breeding management, and failure to do so leads to cows not being bred. This commonly causes an erroneous snap diagnosis of "anestrus." The diagnostic exercise required is not a laboratory one, although whether a cow has been in estrus or not can be inferred from blood or milk levels of progesterone. A careful clinical examination of the ovaries of so-called anestrous cows is required to demonstrate whether they are, in fact, cycling. As a subset of this group, a careful watch for a high proportion of nonpregnant cows among those presented for pregnancy diagnosis is also useful.

2. Breeding cows at the wrong time. The insemination of cows not in estrus, or cows that are pregnant, is one of the

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disadvantages of an artificial breeding program. The timing of insemination relative to ovulation is also important. Cows should be inseminated approximately 12 hours after first observed standing estrus (the AM/PM rule). Herds suspected of inseminating cows at the wrong time should be investigated using results of milk progesterone assays, breeding records analysis, and palpation of the reproductive tract.

3. Nutritional stress. Inadequate nutrition, mostly by way of an insufficient supply of energy, is a common cause of reproductive inefficiency. This may be due to an absolute shortage of feed or a shortage relative to a high milk yield. The cow's change in body condition in early lactation and milk yield are both good indicators of the cow's nutritional status. In addition, dry matter intake and feeding program evaluation are the next step, including forage analysis.

4. Infectious agents. Infectious diseases causing embryonic and fetal loss are summarized in Table 7-5. These are the diseases that lend themselves to diagnosis by laboratory examination of the entire aborted fetus and placenta as well as additional diagnostic tests. Although the infectious agents usually account for few of the infertility problems in dairy cattle and are specifically isolated in only 23% to 46% of the abortions in fetuses submitted to diagnostic laboratories, they are still a significant cause of loss in certain individual herds (Barr and Anderson, 1993).

Laboratory Investigations

Feed Analysis

A complete analysis of the feed for energy, fiber, protein, and minerals provides the best indication of overall nutritional adequacy in the herd. This needs to be accompanied by an accurate estimate of total daily feed intake per cow. The reader is referred to Chapter 11 for information on ration analysis and interpretation.

Milk Urea Nitrogen

Milk urea nitrogen (MUN) is a measure of protein nutrition that can potentially impact reproduction in dairy cows. Research beginning in the early 1990s has indicated that excess protein in the diet of lactating dairy cows is associated with both increased costs of feeding and depressions in cow fertility (Elrod et al, 1993) as well as with excess environmental nitrogen accumulation (Jonker et al, 1998). The decreased fertility in the Elrod study was associated with a lowered uterine pH, which was itself correlated with increases in ration degradable intake protein. In a recent review, Butler (1998) suggests that a urea value of 19 mg/dl in serum is associated with changes in uterine physiology based on increased secretion of PGF after exposure of endometrial cells in vitro to elevated urea concentrations. This response could plausibly explain the observations of decreased plasma progesterone and lowered fertility in cows fed excessive amounts of protein.

Milk samples for urea evaluation are normally taken during a given dairy's regular milking times. Assuming no major changes in the ration, the resulting values for most dairies vary primarily with regards to when the milk sampling occurs relative to feeding. Ferguson (1999) reported an approximate 2 mg/dl difference in MUN determinations between milkings, when feeding occurred between those milkings (mean prefeeding milking, 12.3 mg/dl; mean postfeeding milking, 14.4 mg/dl). However, the range of individual samples for each milking were largely unaffected (prefeeding milking, 7.6 to 20.6 mg/dl; postfeeding milking, 8.2 to 20.1 mg/dl) by timing relative to feeding. DHIA values for MUN are composites of samples taken on test day, therefore they include both milkings for a twice-a-day milking dairy. Such a sampling modality should show less variability resulting from feeding protocols than would an individual-level sampling strategy.

MUN samples are best evaluated as means of small groups because individual animal samples are too variable and bulk tank samples are too crude for an average analysis. The number of animals required for credible analysis is not set in stone, however a common recommendation for the minimum number of animals required is to sample at least eight animals per group of interest (fresh cows, high producers, heifers, etc.), or at least 10% of each group of interest, whichever is greater. However, other authors recommend higher numbers for accuracy: a minimum of 25 animals per group (Jonker et al, 1998), or even all cows in the herd or group (Hopkins, 2000). For small herds it may be most feasible to sample the entire herd and run stratified analyses on the data. To establish consistency over time (thereby allowing development of a herd- or group-level comparison baseline), samples should be taken from the same milking each time and have the same laboratory analyze those samples each time. In addition, cows should be visibly healthy and eating and should have moderate-to-low levels for SCCs.

Given the inherent biological variability in determination of MUN concentrations, it is not surprising that the recommendations for target levels are also somewhat variable. However, most authors agree that averages between 10 and 14 mg/dl should be considered normal (Ferguson, 1999). Ninety-five percent of individual animal samples likely vary between ±4 mg/dl (Grant et al, 1996) to ±6 mg/dl (Ferguson, 1999) beyond the group's mean value. Access to a minimum 2- or 3-month historical baseline for the group in question is essential in the evaluation of any single test's results. Interpretation of MUN tests is based on protein:energy nutrition. Elevated levels (≥16 mg/dl) are often indicative of excess dietary protein, deficiencies in rumen-available fermentable carbohydrate, or improper combinations or ratios of protein to fermentable carbohydrate. Low levels of MUN (<10 mg/dl) are often indicative of deficient levels of ration protein, inappropriate ratios of degradable to nondegradable protein, or excess rumen-available fermentable carbohydrate. It is imperative, however, that any MUN interpretation *not* be completed in a vacuum; it is one aspect of an overall nutritional workup for a herd and, as such, should be used in combination with evaluations of the ration, the ration's components, and the feeding practices on a farm.

Metabolic Profile Tests

Determination of blood urea nitrogen (BUN), serum copper, glutathione peroxidase for selenium deficiency, serum calcium, and phosphorus levels can provide a guide to the cow's nutritional status with respect to each of these dietary ingredients. With the exception of selenium status and perhaps BUN, metabolic profiling has been largely unrewarding as a diagnostic technique because the animal's basic homeostatic mechanisms try to hold blood parameters at normal, even in the face of severe nutritional imbalance.

Tissue Samples

Analysis of liver and other body tissues for minerals such as copper may be indicated in grass-fed dairy cattle.

Fetuses and Placentas

For abortion investigations, submission of samples to diagnostic laboratories should include entire aborted fetuses and their placentas as well as other appropriate samples (Table 7-5).

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Semen Evaluation

If estrus detection accuracy and insemination timing and technique is acceptable, an unexpected decrease in conception rate should prompt a laboratory evaluation of the semen.

Genital Fluids and Discharges

Samples of fluids from the uterus, cervix, or vagina of the cow or the prepuce of the bull may be taken for microbiological culture and identification (Barr and Anderson, 1993). Careful sampling and/or special transport media are necessary when certain genital infections such as mycoplasmosis, trichomoniasis, or campylobacteriosis are suspected. In addition, samples of uterine fluid from cows suspected of having infection of the uterine tubes should be submitted for isolation of both aerobic and anaerobic bacteria.

Abattoir Specimens

When possible the evaluation of the reproductive tracts of cows culled for infertility may provide the practitioner with additional information.

Corrective Action and Monitoring of the Results

Having made a definitive diagnosis, the next steps are to introduce corrective measures and monitor the effects. Corrective actions may include improvement in the surveillance of estrus detection, the use of estrus detection aids, improvement in the feeding program, the specific treatment of cows, and training in proper insemination technique. Before implementing the new change, some consideration should be given to whether the program is less costly than the problem, and value of the program should be weighted by its probability of success. The specific nature of the corrective action should be documented for future reference, and the results should be monitored and recorded. Failure to achieve the desired results may necessitate a reinvestigation of the problem in greater depth.

REPRODUCTIVE PARAMETERS FOR MEASURING SUCCESS

General Comments on Reproductive Indexes

Anyone looking at any of a number of typical dairy records systems will immediately realize that the industry measures "reproduction" in many ways. Whenever such a situation occurs, the industry is trying to say three important things. First, the thing being measured is considered so important that they are willing to expend a great deal of time and effort to measure it sufficiently. Second, no single index is obviously capable of yielding the complete picture, hence, they evaluate several different ways to capture it. Finally, it is a complicated thing; each index must be giving a slightly different perspective on the amorphous thing. Reproduction in modern dairies fits this purpose nicely: it is vitally important and can be quite complex to grasp. So reproduction is viewed in a number of ways.

In most cases the economically motivated objectives for a reproductive program are not the parameters most closely discussed as veterinarians monitor the efficiency of reproduction on dairies. This is largely because most veterinarians do not have access to sufficient data to make economic estimates. Instead, veterinarians tend to focus on the more direct biological outcomes of the reproductive process. Reproductive outcomes such as days from calving to conception (days open), conception rates, measures of estrus detection efficiency, and disease and abortion rates are of primary importance in the analysis of dairy reproductive programs. Many of these indexes are strongly correlated with total herd profitability; however, be aware that veterinarians are following proxies for herd financial performance, not the performance itself.

Specific Indexes Common to Most DHIA-Based Records Systems

Some of the more common indexes reported by major records systems, and followed by those wishing to monitor herd-level reproductive performance, are listed in this section. The following section describes some of the techniques the consultant can use to garner more information from these indexes.

Average Days Open

Average days open (or days in milk to conception) is commonly seen as the "bottom line" measure of the efficiency of a dairy herd reproductive program. It represents the average interval from calving to conception in a herd. This measure is significantly confounded by culling policy and the policy by which cows are included in the calculations (Fetrow et al. 1990). As veterinarians have become more adept at records analysis, they have begun to examine not only the average days open but also the distribution of days open. It is possible to have a generally acceptable average days open but with significant number of cows at costly extremes of that average (Ferry, 1992).

For instance, Fig. 7-3 demonstrates a cumulative sum graph of "days in milk at conception (days open)" for two hypothetical dairy herds. The figure reported by DHIA is the average "days open." The two herds are only 2 days apart in this index (i.e., Herd A = 112, Herd B = 114); hence, it would be normal to think neither herd was doing exceptionally better than the other. However, if the practitioner evaluates not the average performance but determines what proportion of each herd achieves our goal range for *days open*, a different story emerges. Assume the management for both herds was targeting a 12.5- to 13.5-month calving interval. That translates to a desired range for *days in milk at conception* of approximately 95 to 125. Note in Fig. 7-3 how 68% of Herd A met the targeted range, but only 39% of Herd B did so. In addition, the practitioner can immediately see that Herd B has problems with animals having too short a "days open" (i.e., 26% of the herd has a "days open" <95) as well as too long a "days open" (approximately 35% appear to have an extended breeding period). For Herd A, less than 12% are being bred too early, and approximately 20% are conceiving late. Although Herd A is doing better than Herd B overall, both herds may have trouble with some late conceiving cows. again, the practitioner would not be able to discover this by looking only at averages.

Average days open is usually a highly skewed number (see Chapter 2 for discussion of skewed data), which makes the use of averages questionable. For example, a current herd with which one of the authors is working has a reported *average days open* of 140. However, the distribution of days open is such that a few very high count cows are responsible for the average figure being higher than that of 60% of the cows. The median days open, representing the lower 50% of the herd, is 123. Hence, half the cows have days open of 17 days or *more* below the mean, and 6 of 10 cows have less than the mean of days open. This is demonstrated in Fig. 7-4.

In many reporting schemes, the actual data being reported are more correctly called *minimum average days open* because cows bred too recently to be examined for pregnancy diagnosis are assumed by the system to be pregnant. Therefore the figures reported will usually be optimistic. The

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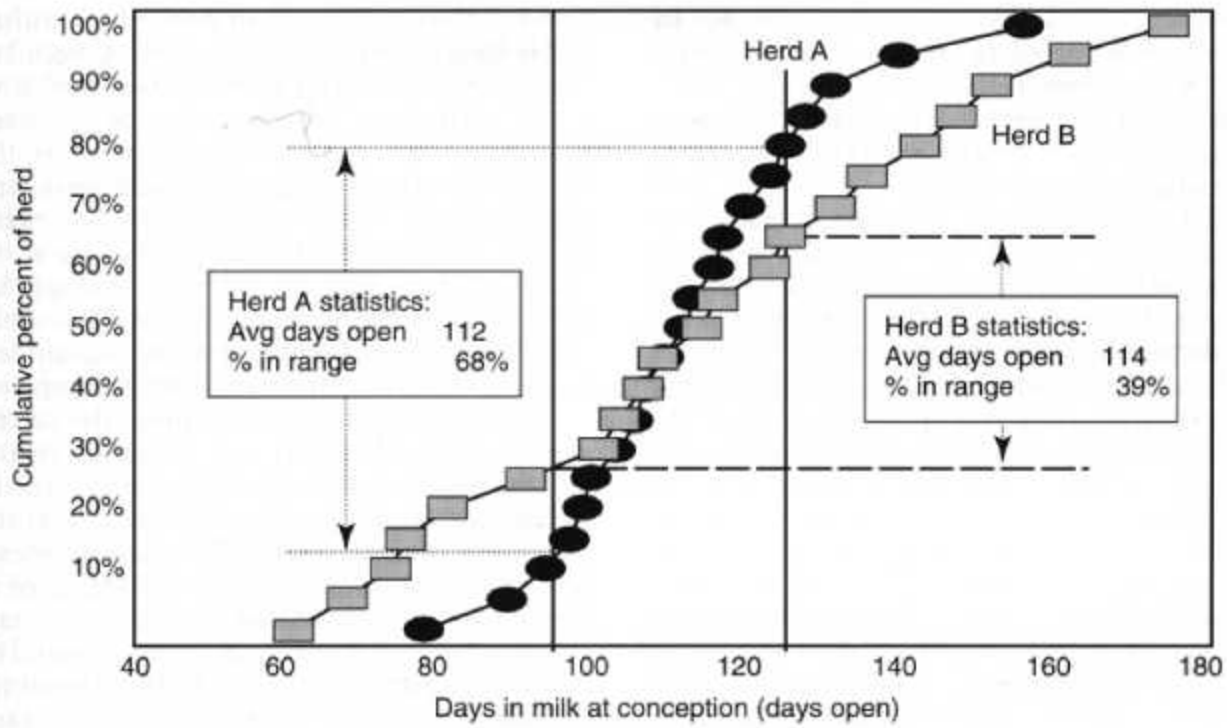

FIG. 7-3 Demonstration of effect of variation in "Days Open" for two hypothetical herds using a cumulative sum graph. Note the two herds have approximately the same value for "Days in Milk at Conception (Days Open)." However, Herd A has over two thirds of its cows in the desired range, and Herd B has only 39% of its cows in the desired range. The average values for "Days Open" would lead the practitioner to believe both herds were on target, when they are not.

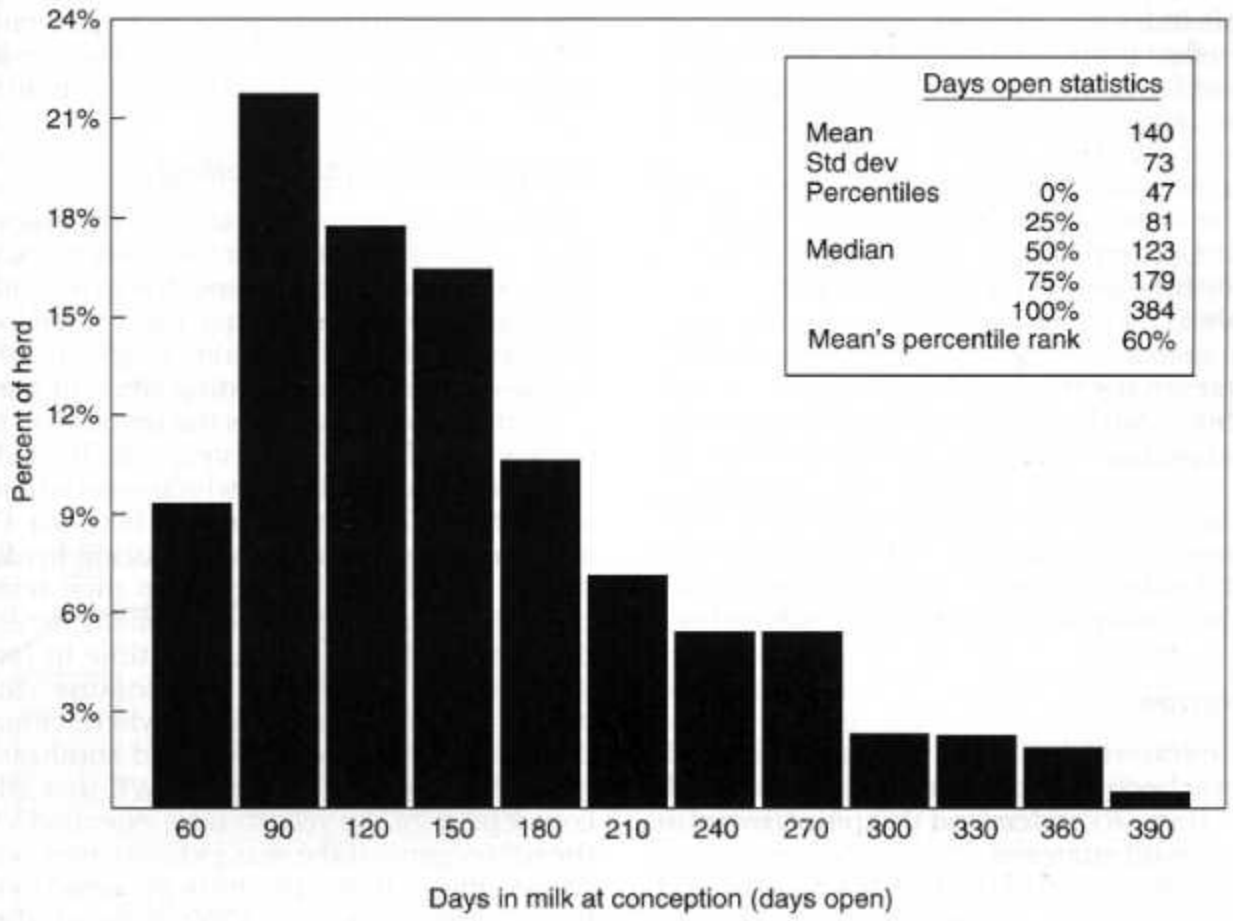

FIG. 7-4 Distribution of days open for an actual 250-cow Holstein dairy in North Carolina. The data are highly right skewed, such that the mean is nearly one estrous cycle greater than the median. Sixty percent of the herd actually has days open that are less than the calculated mean. Hence the usual index followed—*average days open*—is a pessimistic view of reproduction efficiency.

only situations veterinarians will commonly face in which this index *will not* be optimistic is in bull-bred herds that do not record heats. In such instances, the only time a cow enters the database is after she is diagnosed pregnant, and a date of conception is back-calculated for her. It should also be noted that a recurring problem with many measures of reproductive performance is also evidenced in *average days open*. In many records systems a cow must be bred to enter into the calculation. As an example of this problem, if a person owned 10 cows and only bred one of them, that single animal's statistics would enter the calculation. If that animal became pregnant on its 90th day after calving, the

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herd's reported *minimum average days open* would be 90. In other words, this index is completely blind to what is going on in unbred animals. However, if the record system allows unbred cows to submit their current days in milk value to the calculation, then the index will still be optimistic, but it will be impacted by nonbred cows.

The DHI-Provo data from Table 7-2 displays averages for this index in the range of 145 to 155 days. Note this is much longer than most references will recommend. Hence, our recommendations are biologically impractical, the published averages are skewed by a low proportion of high-days-open cows, or producers have found that achieving our recommendations is not cost effective. It is likely that the second reason predominates; however, all three reasons likely apply.

Calving Interval

The measurement of the calving interval—that is, the period from one calving to another—is too historical to be of real value in the regular assessment of reproductive performance in continuous calving herds. To obtain a mean figure for the herd, all cows must calve twice so that the calving index includes events that, for some cows, could be 1.5 to 2 years in the past. Thus cows that are reproductive failures— those cows that fail to be bred, conceive, and carry a calf to term—are not included in this index. In addition, in many recording systems, a cow contributes her value to the herd summary as soon as she calves, and it remains until she calves again. In others, this index is calculated based on breedings and may therefore reflect more current practices on the farm. Either way, the figure for calving interval is often heavily affected by past events and can have little to do with what is currently going on in the dairy. Thus average days open is the preferred general measure of overall fertility for current practices. The reader is referred to the previous "Different Strategies, Different Optima" section for a discussion of the difficulties in establishing goals for calving intervals.

The data in Table 7-2 suggest average dairy performance for calving interval is in the range of 13.7 to 14.1 months. Again, this is higher than the standard 12-month, or 12.5- to 13.5-month, recommendation commonly found in the literature. Likely, the reported values for calving interval are skewed upward by a few extended lactation cows. However, it should be noted that not all clients will reach the recommended calving interval. It is important to remember that to get an average of 13.7 to 14.1 months, some herds were lower and some were higher. Likely, some herds were *much* higher.

Days in Milk, Average

At first glance this index, which is simply the average length of time the cows have been milking, has nothing to do with reproduction, but it does. To understand this point, we must digress and discuss dry-off strategies.

The reasons most cows are dried off are because either (1) the cows are within 60 days or so from calving and are dried off to give the cows a chance to involute and prepare for a new lactation, or (2) the cows' milk income no longer covers the cost of milking them, so they are turned dry to await another lactation. It is evident that reproduction plays the major role in both decisions; if a cow is bred at an appropriate time and has not suffered untoward diseases or traumas, she should be turned dry for the former reason—because she is within 2 months of calving again. Hence, a herd that has abnormally high *days in milk* indexes is also very likely to be suffering from poor reproduction.

Be aware that the index just mentioned is not without its problems. Because *days in milk* is an average over all cows, it also has the problem of all averages. For instance, for the two herds designated in Fig. 7-3, Herd A would show an "average days in milk" of 198 days, while Herd B would show 198 days, assuming the calvings were equally distributed throughout the year. Remember, however, that Herd A would be considered the much better managed herd once the distribution of *days in milk at conception* was examined. Therefore *average days in milk* also misses the effects of distribution. In addition, this measure can be altered quickly through selective culling, calvings, or drying off. As a result, it is most helpful to follow this index over time. Any sudden jumps one way or another may be due to culling, calvings, or mass dryoffs.

All lactating cows contribute to the calculation of *average days in milk*. A cow is still included in this measurement whether she is bred or not. Hence, *average days in milk* is one index that *is not* blind to nonbred cows. It can provide the analyst with a measure that encompasses all cows in the herd. Furthermore, by taking advantage of what is normally considered a weakness of averages, it is very sensitive to extreme values. As a result, as cows calve and enter the herd, or if cows are allowed to stretch their lactation to well beyond normal, or if groups of cows are culled or sent to the dry lot, *average days in milk* will rapidly change, allowing an analyst to identify periods when such events are taking place. All of these events are important to remember because they can also impact interpretations of milk production and other measures of reproduction.

Table 7-2 suggests an average performance for *average days in milk* of just under 205 days. As with the previous indexes, this is beyond the commonly suggested range of 150 to 180 days by one or two estrous cycles. The previously mentioned potential reasons for this discrepancy hold here as well.

Days in Milk, First Breeding

Also known as *days to first service*, this index is simply the average postpartum time for the cows to be bred for the first time. Some researchers consider it one of the most important factors in determining the overall performance of a dairy's reproductive program (Ferguson, 1995). It is affected by the choices made regarding when to start breeding cows.

In most records systems the term *option period* or *voluntary waiting period* (VWP) is listed, which signifies the postpartum time, in days, during which cows will not be bred. Typically, the VWP of most farms is between 45 and 55 days in milk; however, many high-producing herds, and herds aiming for 365-day milk records on their registered cows, will opt for higher VWPs. However, many herds choose to breed their first calf heifers at a later time in lactation than they might their cows, which will confuse what VWP actually means. Furthermore, in areas where climate affects reproduction (e.g., the southwest and southeast United States), many herds use a "variable" VWP that allows cows in the cooler parts of the year to have extended VWPs and cows in the hotter parts of the year to have shortened VWPs. Another confounder is that intensively managed herds may combine this seasonal variance in VWP with consideration of an individual cow's milk production, such that higher-producing cows may be given extended VWPs relative to their lower-producing peers. Finally, most DHIA processing centers default to a 60-day VWP if the dairy does not enter one in their record system. Hence, although records systems happily report a set VWP for a farm, the consultant must be aware that the listed figure may only apply to a certain proportion of the herd throughout the year, if at all.

Days in milk, first breeding is often interpreted as a strong measure of estrus detection capability in a herd. To do this, of course, one needs to know when the herd "wanted" a given cow to be bred, relative to what the *days in milk, first*

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breeding indicates. If a herd is aiming for a 12-month calving interval—meaning *days in milk at conception* will be targeted in the 85 to 90 days range—then *days in milk, first breeding* by necessity will need to occur in the average cow before the period of 85 to 90 days in milk. Again, more in-depth use of this variable is discussed in the following section.

In bull-bred herds, *days in milk, first breeding* is primarily a historical index. It is historical because the only data going into it, in most bull-bred herds, are the calculated days in milk at conception—data that are discovered only at pregnancy examination. Thus the index loses most of its ability to describe estrus detection intensiveness and therefore its primary value in bull-bred herds.

The data from DHI-Provo, shown in Table 7-2, indicate that *days in milk, first breeding* for most dairies fall in the range of 79 to 95 days. This range is approximately one to nearly two estrous cycles longer than the commonly recommended value of 60 days, so some of the previous reasons why the typical farm is not reaching the recommendations will hold. Furthermore, if these herds were not targeting a 12-month calving interval, such a difference would be expected. However, should the individual cow's *days in milk, first breeding* be right skewed, a published range such as that in Table 7-2 could be misleading.

Estrus Detection Rate

Also known as *percent heats bred* or *percent heats detected*, this parameter measures the *intensity* of estrus detection but not the *accuracy* of estrus detection. The former assesses whether it is being done at all or at a reasonable level; the latter determines whether it is being accomplished precisely. It is possible to have high apparent estrus detection intensity and poor reproductive results. The insemination of cows not in estrus can be a serious problem on small as well as large dairy farms (Reimers et al, 1985; Slenning and Farver, 1990). Obviously, these cows do not conceive when bred.

The relationship between estrus detection intensity-accuracy and overall reproductive performance is worth consideration at this point, because it is often not considered (Fig. 7-5). Assume that someone is hired to breed cows who knows nothing about estrus detection. To get some cows bred, this person opts to bring in every cow every day and breeds them all. Of course this will not be a very effective strategy; the majority of cows will not be in estrus at the time of breeding, so conception rates will be essentially nil. However, the records will indicate that estrus detection would be very high. In terms of clinical test efficiencies, such a strategy would show a 100% sensitivity and no specificity; there would be no false negatives but many false positives. This coincides with the bar and area section of the left side of Fig. 7-5. Now imagine a second situation in which the person performing estrus detection will only identify those cows that stand to be mounted, have a clear mucus discharge, and are very active, as being in estrus. These cows will likely be highly fertile because they will be identified at the ideal times to be inseminated. Hence, conception rates will be high. However, estrus detection rates will be quite low because few cows display all the signs of estrus at any one time. In terms of test efficiencies, this strategy will have a very high specificity (few false positives) but would have a fairly low sensitivity (many false negatives). This corresponds to the situation at the far right of Fig. 7-5. At either extreme, when estrus detection appears to be very high, or when conception rates appear to be quite high, overall herd performance will suffer. The proper balance between estrus detection intensity and accuracy exists, however, at points in between these two extremes, as shown by the curve in Fig. 7-5.

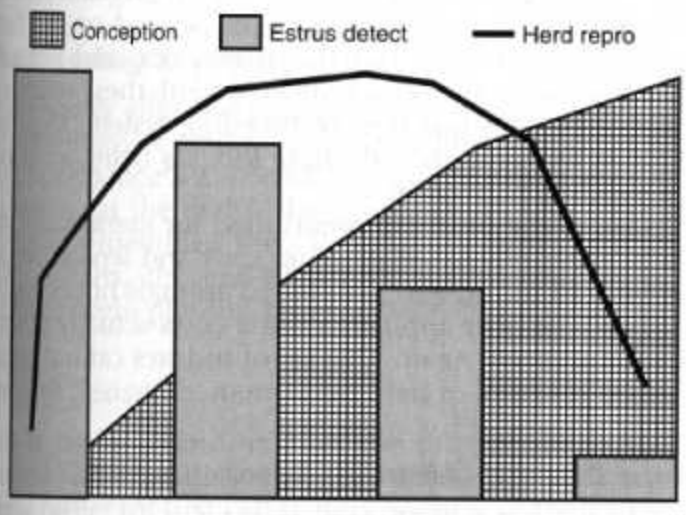

FIG. 7-5 Graphic depiction of the interplay between estrus detection intensity and overall conception rate. When estrus detection rate is extremely high, many cows not truly in estrus will be identified and bred. As a result, conception rates will decline. Conversely, at very low estrus detection rates, only those cows most profoundly showing estrus behaviors will be bred, and these animals will tend to become pregnant. As a result, conception rates will increase. The best overall herd performance will occur when neither measure is at an extreme, as suggested by the "Herd repro" curve.

The commonly used index for estrus detection is *percent heats bred*, which is a comparison of the calculated number of estrus events that a herd should have seen against the actual reported number of events, each over a specified period. Most of these systems assume the involved cows have a 21-day estrous cycle. Thus, all things being equal, one would expect to see approximately 30/21, or 1.4, estrus events per cow per month. From this estimate must be subtracted the succeeding interval in which the reporting date is too early for pregnancy determination. Simply stated, if the herd has three cows in the breeding window and follows them for 1 month, a person would expect to have seen at least four heats (average of 4.3). If the dairy reported two estrus events from the three cows, the *percent heats bred* would calculate to 2/4.3, or 46%. Again, the calculation is not quite this simple, but this example serves to make the point.

Note that the estrus detection rate is one of the few indexes discussed that captures all the cows. It is not blind to nonperforming cows, as are *average days open* and *services per conception*. However, in modern times this index has been proving of decreasing value because it has a "hardwired" assumption of a 21-day cycle for cows. With current trends of increasing use of hormonal manipulation of the cows' estrous cycle, and the concomitant alteration this manipulation causes in the length of the cows' cycles, the 21-day assumption becomes harder to support.

In many dairies, *percent heats bred* can reach above 80% for long periods when management focuses on heifers. In the milking herd, such levels of long-term performance are difficult to maintain for a variety of reasons. It is not uncommon for well-managed herds in either the southeast or the southwest United States to achieve monthly levels of milking herd *percent heats bred* of 80% or higher in the cool parts of late winter and to be capable of only reaching 35% to 40% during the heat of summer. This 50-percentage-point difference seems to hold whether the cool weather maximum is 80% or 60%; the mid-summer drop will be to 30% or 10%. Certainly, in more "cow-friendly" climates, this kind of seasonal impact on estrus detection will not be as severe. However, when working with the milking herd, pushing the system to exceed 70% estrus detection rates (without hormone analysis) is likely to lead to inaccuracy and be counterproductive

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for most dairies. Even if estrus detection remains accurate, there appear to be diminishing economic returns to improvements at estrus detection beyond 70% (Oltenacu et al, 1981; Rounsaville et al, 1979).

As was the case for *days in milk, first breeding*, the index *percent heats bred* is of little value in bull-bred herds, because most of these farms only record estrus events on which the cows became pregnant. Other heats are often not observed and therefore not recorded.

Table 7-2 suggests that a typical dairy will show a *percent heats bred* at approximately 43% to 52%. As mentioned above, before deciding how well or how poorly a given herd is doing in this regard, a veterinarian should consider the confounding factors such as weather, production, herd age structure, and management goals. For any given farm, this index will show a great deal of variation across time and production.

First Service Conception Rate

This index is considered by many researchers to be one of the best predictors of overall reproductive program success and, along with *days in milk, first breeding*, should be the focus of farm resources ". . . to exert the greatest control on reproductive performance. . . ." (Ferguson, 1995). *First service conception rate*, also called *conception rate to first service*, is calculated by determining the proportion of animals that became pregnant on their first service. It is the result of combining estrus detection accuracy and breeding technique. Thus low values for this index can result from poor estrus detection and/or errors in AI technique; it cannot be considered as a pure measure of either.

Similar to the previous two indexes, *first service conception rate* is of little to no value in a bull-bred herd. In most reporting systems, a bull-bred herd will show this index at 100%. Only one breeding is recorded (the back-calculated date of conception from the estimated stage of pregnancy at the pregnancy examination), so conception rate is apparently perfect. If only this were true.

Data from Table 7-2 indicate most dairies reach a 42% to 54% range of performance regarding *first service conception rates*. This is much lower than the commonly recommended goal of 60% or more from the literature. The possible explanations for such a discrepancy mentioned previously for other indexes are likely valid here.

Services per Conception

This index is often reported in two forms: *services per pregnancy, pregnant cows* and *services per pregnancy, all cows*. The differences are what numerator is used and how the indexes are interpreted. For instance, assume a three-cow dairy herd has cows identified as A, B, and C. Over the period in question, you bred cows A and C once and cow B twice. Cows A and B were later found pregnant to their respective breedings. To calculate *services per pregnancy, all cows*, count the number of services applied to all the cows in the herd ($1 + 1 + 2 = 4$) and divide this sum by the number of cows becoming pregnant to those breedings (2). Thus 4/2, or 2.0, *services per pregnancy, all cows* was yielded. To calculate the value for *services per pregnancy, pregnant cows*, the analyst counts the number of services applied only to cows that became pregnant. In this example the number would be three ($1 + 2$) services applied to cows that became pregnant. Again, divide this figure by the total number of cows becoming pregnant (2) to get *services per pregnancy, pregnant cows*. For this example, *services per pregnancy, pregnant cows* is 3/2, or 1.5.

At times, persons or systems may report conception rates on a "per pregnant cow" or on an "all cow" basis. To convert the previous *services per pregnancy* indexes to conception rate indexes, simply take the inverse of the former. For example, in the previous situation, the *conception rate, all cows* would be 1/2, or 50%, and the *conception rate, pregnant cows* would be 1/1.5, or 67%.

Interpretation of these indexes is fairly straightforward. The "pregnant cow" figures are usually taken as measures of the efficiency of conception when fertile cows are bred. Of course, this definition is somewhat teleological, for our definition of "fertile" is simply the number of cows the herd got pregnant; there are likely many more "fertile" cows in the herd, but we cannot identify them. Be that as it may, it is a rough proxy for the "male" side of the insemination process: semen quality, insemination technique, timing of insemination, and accuracy of estrus detection. The "all cows" measure includes all breedings in the herd, whether the cow ultimately became pregnant or not. Hence, it is usually a better measure of overall herd conception efficiency. If *services per pregnancy* in all cows is significantly larger than *services per pregnancy* in pregnant cows, then there must be problem breeder cows in the herd.

The *services per pregnancy, pregnant cows* and *services per pregnancy, all cows* indexes are confounded in some herds by factors that affect all cows, such as inadequate nutrition, heat stress, and infectious infertility. Depending on climatic conditions and how soon postpartum cows are bred, *services per pregnancy* in pregnant cows could be in the 1.5 to 2.5 range. According to Table 7-2, however, typical performance levels for this index run in the range of 1.9 to 2.4.

The reader might reasonably ask why the ultimate goal for *services per pregnancy* is not 1.0. The reason is fairly simple: for a breeder to achieve near perfection in outcome, the breeder must only work with nearly perfect cows, both behaviorally and physiologically. Thus, to achieve exceptional performance, the breeder must bypass some cows as "not quite there yet." Unfortunately, few cows ever display "perfect" estrus events, so some cows will nearly always be deemed inappropriate for breeding. The end result is that those cows being bred will likely be the most fertile, so the breeder will develop outstanding *services per pregnancy* values, but the herd's overall reproductive performance will be decreased. This is, again, the situation to the far right of Fig. 7-5. Such a dichotomy could occur whenever the value of this index drops below 1.8. So be careful; "better" is not always better.

Because both the *services per pregnancy, pregnant cows* and *services per pregnancy, all cows* indexes depend on the herd's management recording individual services, and since this rarely occurs accurately in a bull-bred herd, these indexes are of little value with this type of breeding system. Most bull-bred herds will end up with these indexes being reported at 1.0, suggesting perfection.

Similar to the problem mentioned for *average days open*, the *services per pregnancy, pregnant cows* and *services per pregnancy, all cows* indexes are "blind" to animals not being bred in the herd—it only applies to those cows actually observed in estrus and bred. Again, this set of indexes cannot be used as a single measure of herd performance.

Various Disease–Abortion Rates

Some sections of this chapter are devoted to specific health-related causes of infertility and pregnancy wastage, and will not be explored here. It is important, however, for a true monitoring system to keep track of such events. It should be noted that most DHIA-based records systems, and many private record services, do not track such data. As a result the effort and motivation to do this largely falls on the consulting veterinarian and herd owner. A veterinarian should not simply assume these data are being collected and analyzed; most often they are not.

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Reproductive Practices Specific for Seasonal Herds

Voluntary Waiting Period and Dry-Off Dates

In these herds the VWP often ends on the same date for all cows, irrespective of when any individual cow calved. In a similar way of thinking, dry-off dates for cows are usually set for the same time and are primarily driven by pasture budgets in pasture-based dairies—budgets designed to ensure that the availability and demand for feed are balanced for the remainder of the season. Important aspects of the reproductive practices for a seasonal herd follow.

Planned Start of Mating

This occurs on the day following the end of the herd's VWP. However, many seasonal herds set the *planned start of mating* for 14- to 16-month-old heifers at 14 days earlier than the end of the VWP.

Prebreeding Period

Cows that were bred very late in the season will often be induced to calve if their estimated calving date is less than 40 days before the *planned start of mating*. At approximately 28 days before the *planned start of mating*, all cows will be evaluated for post-parturient reproductive problems such as retained fetal membranes, metritis, and pyometra.

Breeding Season

The breeding season usually runs for 6 to 8 weeks. Mating will often be accomplished using artificial methods for the first 4 to 6 weeks of the breeding season. Bulls are usually brought in for the remaining 4 to 6 weeks of the breeding season. At 21 days into the breeding season, veterinary examinations are usually conducted on all nonbred cows. It is not unusual for the veterinarian to find that most of these cows in grass-fed dairies are in anestrus because of negative energy balance. At 45 to 55 days after the end of the AI part of the breeding season, all cows not seen to return to service are usually scheduled for pregnancy examination. At a similar period after the end of the breeding season, all cows not previously identified as pregnant are usually examined.

Postbreeding Season

In the weeks after the final pregnancy examinations several records-intensive actions are taken. First, the overall breeding performance is assessed. Second, cull cows are identified for culling at the end of lactation. Third, late calving cows are usually identified for scheduling in their induction program. Finally, the end-of-season pasture budget is established to begin planning for the best dry-off times.

Calving Season

This is set for 280 days after the start of the last season's *planned start of mating*. As mentioned above, it may start 2 weeks earlier for first calf heifers because of their earlier start of breeding.

Reproductive Indexes Commonly Used in Seasonal Herds

Seasonal herds often follow the same indexes as mentioned above. However, other data can prove to be of value, oftentimes of more value, in these systems. The primary reason is that seasonal herds need to develop data sources that can be collected and analyzed in only a few weeks—anything longer than this would make the index irrelevant to breeding management.

Calving Rate

This index is calculated as the percent of cows calving during a stated period. In most cases, the period is 14 days. Typical goals for this index are to have 30% to 40% of the herd calving in the first 2 weeks of the *calving season*. For each 2-week period following, the goals are often an additional 30% to 35% of the herd calving for weeks 3 and 4, 20% to 25% for weeks 5 and 6, 10% to 15% for weeks 7 and 8, and 5% for the final period, if needed. This index allows a veterinarian new to a farm to establish how well the past season went.

The values for *calving rate* can be broken down by parity. If older animals were calving late in the season, it is possible pasture quality was an issue. If younger animals were calving late, then pasture quantity may have been an issue.

Premating Heat Rates

This index evaluates the estrus detection capability of the herd management for the 24 days immediately preceding the *planned start of mating*. A typical goal is 80% to 90%. If it is lower than this, the herd will have difficulty achieving a 6-week breeding season. Higher values for *premating heat rates* may suggest that estrus detection is inaccurate, leading to unacceptably low conception rates and extended breeding seasons.

As with *calving rate*, this index can be broken into parity-specific rates. In general, one expects the first calf heifers to have relatively low *premating heat rates*, oftentimes 5% to 10% lower than those of older cows. For third lactation and higher cows, the number should be close to 90%. For animals calving in the 40 days before the *planned start of mating*, the values for *premating heat rates* will be much lower—often only 20% or so. If the values are lower, management should evaluate whether the problem is lack of estrus detection or decreased estrus activity.

Submission Rates

This index represents the quantity of cows bred each week, or each 2-week period, of the *breeding season*. It is usually reported as a cumulative percentage. It is a direct measure of estrus detection efficiency. The values for the weeks 1 through 6 of the breeding season can be reasonably set at 30%, 60%, 90%, 93%, 97%, and 100%. Again, this index can be evaluated on a parity basis or on a basis of whether the cows had calved more than 40 days before the start of breeding or not.

Returns to Estrus Rates

This index can be a valuable measure of estrus detection accuracy. If previous estrus detection was accurate, only 10% to 12% of cows should be found coming back into heat before 17 days. As before, this should only be evaluated in cows in which prostaglandins are not used.

In-Calf Rates

This index is calculated as the percent of cows becoming pregnant during weekly or biweekly segments of the *breeding season*. It is usually reported as a cumulative percentage of the cows available at the start of the season. This index will reflect the same dynamic as that shown for *calving rate*. Therefore reasonable goals for *in-calf rates*—for biweekly evaluation—would be 33%, 65%, 87%, 97%, and 100%.

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Tools to Expand the Value of Standard DHIA-Based Reproductive Indexes

Expanding the Possibilities

The previously described reproductive parameters are the bases for most analyses of dairy herd reproduction. A few things can be done with them to bring out more information about what is going on in the herd. The techniques are largely based on farm-specific assumptions and/or other, non-DHIA, data.

Percentage of Possible Estrus Events Detected

Work performed in 1974 suggested that fewer than 5% of dairy cows remain anestrus by 40 days in milk (Britt et al, 1974). It is likely that with the ensuing quarter century's increase in production, this number has increased. Nevertheless, the true proportion of anestrus cows in a well-fed confinement farm should be near this figure. However, in a grass-fed, nonsupplemented dairy, should the weather have delayed pasture production relative to the herd's calving season, anestrus cows by 40 days in milk may be quite common.

As mentioned previously, estrus detection is fundamental to reproductive success and is usually the weak link in any AI-based dairy's reproductive program. Unfortunately, many of the indexes used in current records systems carry with them a large proportion of historical data, which makes them fairly insensitive to changes in the herd's condition or performance. Hence, these reproductive indexes may not respond quickly enough to identify trends in performance. Luckily, there are other means to establish monitoring indexes that better reflect current situations.

Pregnancy Rate at Pregnancy Examination. Perhaps the simplest of the "real-time" measures, this determination of the proportion of cows held for pregnancy examination that were, indeed, pregnant yields a powerful indicator of estrus detection efficiency over the previous month or more. The reason this works is simple: A dairy operator will only hold up cows for pregnancy examination when that producer feels the cow is actually pregnant. Had the operator seen the cow in heat after a breeding, the cow would have been rebred, her pregnancy examination would have been delayed, and she would not have been presented for examination. The process to calculate this index follows:

1. Count the number of cows presented for pregnancy examination. Be certain to exclude, for example, any animals held for standard pregnancy rechecks or pre-dry-off examinations (Value A).
2. Count the number of these cows that were diagnosed pregnant. Include animals declared pregnant but possibly in process of losing the pregnancy. If she conceived to the breeding, she is counted (Value B).
3. Of the cows found nonpregnant, count the number that are apparently anestrus and/or have cystic ovaries. Include severely lame cows. Also take into account animals that, in the past month, had disease events causing sepsis, such as severe mastitis (Value C). The total count of these animals, which represent those cows likely to not have shown signs of estrus associated with normal estrous cycles, is subtracted from the count in Value A (the number of animals submitted for examination). This is done because those cows, because of extenuating circumstances, were abnormal in such a way as to make them not eligible for conceiving, maintaining a pregnancy, *and* displaying normal signs of estrus.
4. Calculate the *pregnancy rate at pregnancy examination* as follows:.

$$\text{Value B} / (\text{Value A} - \text{Value C})$$

Interpretation of the *pregnancy rate at pregnancy examination* index is fairly simple: the higher, the better. Reasonable goals appear to be in the 70% and higher range. Again, this will be strongly affected by season. Our experience has been that a producer may consider late winter/early spring-time performance for this index as unacceptable if it drops below 80%, yet may consider itself as doing well if, by late summer, the same index is in the 50% range. In addition, the length of time from breeding to pregnancy examination will affect the interpretation. For example, suppose the veterinarian usually schedules pregnancy examinations for 45 days or more after insemination, instead of 35 days or more after insemination. Any cycling cow found nonpregnant will likely have had two estrus events since breeding, whereas at the 35-day check the typical cow will have had only one. Hence, cows found open at a 45-day pregnancy examination suggest management missed more than a single estrus event.

Other Ways to Calculate Estrus Detection. In addition, there are other ways to calculate estrus detection, should the reporting system a client uses not give the information. Sometimes the consulting veterinarian may not know how a program calculates a figure and simply wants to check on the data being given. The following indexes can help in both situations.

Percent of Breedable Estrus Events Detected (%BEED). This index of estrus detection focuses on "breedable" estrus events—those heats that occur *after* the end of the herd's option period or VWP. To calculate the percentage the practitioner needs to know the *average days open*, VWP, and either the number of heats per cow detected or the conception rate. It is calculated as follows:

$$\text{Breedable heats} = \{[\text{Avg days open} - (\text{VWP} + 10)]/21\} + 1$$

As an example, if a herd had an *average days open* of 147, a VWP of 55, and a 50% conception rate, this herd's breedable heats would be $\{[147 - (55+10)]/21\} + 1$, or 4.9.

To calculate %BEED, divide the average number of heats observed per cow (this can be assumed to be 1/conception rate, or $1/0.5 = 2$, should the count not be available) by the breedable heats and multiply by 100:

$$\begin{aligned}\%\text{BEED} &= (\text{Heats detected per cow/breedable heats}) \times 100\\ &= (2/4.9) \times 100\\ &= 41\%\end{aligned}$$

CAVEATS. Note that this index assumes the cows follow the standard physiological interestrus interval of 21 days and that the listed VWP is appropriate for all cows. We know that not all cows cycle every 21 days and that dairies treat cows differently regarding VWP. Furthermore, if a herd makes use of prostaglandins to any major degree (remember, the USDA-NAHMS survey in Table 7-1 suggests that perhaps one in five dairies expose at least 50% of their cows to prostaglandins), this will make the 21-day assumption invalid. However, if the dairy's use of prostaglandin is fairly constant over time, this index can be a useful "yardstick" for within-herd comparisons. The practitioner will not be certain the figure derived is accurate, but changes in the figure will very likely signify alterations in the actual process being monitored. However, it will not be advisable to use this index in between-herd comparisons.

The "VWP + 10" segment is a built-in assumption as to when the typical cow will cycle. It assumes most cows will cycle in a 21-day period, and that half of them will cycle in half that period. Hence, the "average" cow should be seen in estrus 10 days after the end of the VWP. On further examination, however, this will not be true in early lactation. This is because most estrus events are clustered in time: first estrus

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after calving is usually between days 16 and 18, the second estrus occurs something on the order of 16 to 20 days later (between 31 and 37 days after calving), and it is not until the third estrus event that cows establish the more typical 18 to 24 day cycle (i.e., between 49 and 61 days after calving). The fourth estrus, then, would occur between 67 and 85 days in milk.

Therefore, for a VWP of 60 days, the practitioner might expect a few estrus no. 3 cows to be cycling on the day following the end of the VWP but would not expect to see the estrus no. 4 cows to start coming into heat for at least a week. The practitioner should not, therefore, be surprised if, immediately after a 60-day VWP, not many cows are identified as being in heat—the biology says that should be exactly what to expect. However, for a 50-day VWP, he or she should expect to be in the phase of estrus no. 3 where more cows will be identified each day for the first 5 days or so and level out for another 6 to 7 days. Then it should get "quiet" again.

The preceding information is not to say that we need to account for each cow's estrous cycle timing to estimate estrus detection efficiency. The computations would be tedious and likely in error, and the results would not be of much more validity than the broad "VWP + 10" assumption. Just be aware that how well such indexes reflect reality will be a function of the actual level of normal cyclicity in the herd and which VWP the dairy operator has chosen.

Estrus Detection Efficiency Using "Breeding Interval." As with the previous index, this index addresses estrus detection after the first breedable estrus event. To calculate it the analyst must know *average days open*, *services per conception*, and either *days to first service* or VWP. First, the analyst must calculate the breeding interval in either of two ways:

$$\text{Breeding interval} = (\text{Average days open} - \text{days to first service}) / (\text{Services per conception} - 1)$$

$$\text{Breeding interval} = (\text{Average days open} - [\text{VWP} + 10]) / (\text{Services per conception} - 1)$$

The estrus detection efficiency is given simply by taking the ratio of the average estrus length (usually assumed to be 21 days) and the breeding interval:

$$\text{Estrus detection efficiency} = \text{Average interestrus interval} / \text{Breeding interval}$$

For instance, suppose a herd's data were the following: average days open = 147; services/conception = 2.4; days to first service = 86; VWP = 55. The breeding interval, using each means to calculate it, would be the following:

$$\text{Breeding interval} = (147 - 86) / (2.4 - 1) = 44;$$

$$\text{Estrus detection efficiency} = 21/44 = 39\%$$

$$\text{Breeding interval} = (147 - [55 + 10]) / (2.4 - 1) = 59;$$

$$\text{Estrus detection efficiency} = 21/59 = 36\%$$

The estrus detection efficiency has the added advantage of representing the estrus detection performance for different groups within the herd, assuming the analyst can get at subgroup data. For instance, it is easy to imagine working the "breeding interval" type of calculation for both pregnant cows and for all cows. In another situation, the analyst might run the calculations by parity group.

CAVEATS. The second of these two equations uses VWP, which, as mentioned previously, may not be appropriate for all cows. They also use *average days open*, which is likely skewed (Fig. 7-4) and therefore a questionable index.

Estrus Detection Efficiency Using Interestrus Intervals. In this index the assumed normal cycle length of 21 days is divided by the average number of days between consecutive services, or by the published *interestrus interval*. As an example, assume a herd displayed an average interestrus interval of 27 days. Its estrus detection efficiency value, using the interestrus interval, would be as follows:

$$\text{Normal cycle length / Interestrus interval} = 21/29 = 0.72 = 72\%$$

CAVEATS. Although this calculation is, by far, the simplest of the three examples given, it suffers from the same problems mentioned above: it assumes the herd's cows are cycling in a 21-day period. Thus the same arguments presented above hold here. The more variable the natural cycle of the cows, and the more use of prostaglandins by the herd's management, the less valid this index will be. As mentioned at the start of this overall section, whenever the practitioner is offered multiple ways to measure something, he or she is being told three things: (1) it is important, (2) no single measure is sufficient, and (3) the topic is complicated. All three hold true for estrus detection.

Indexes to Help Determine Allocation of Reproductive Inefficiency to Different Management Areas. Often identification of a herd in reproductive trouble is not difficult. The tricky part is deciding what aspects of reproductive management are lacking and, of those, which appear to be the major limiting steps in the process. For most AI herds a good way to start this process is to evaluate whether the losses are primarily due to estrus detection or to problems with conception. They all depend on *average days open*, a figure previously mentioned as suffering from some problems. The "days lost" calculations also assume all cows have a 21-day estrous cycle, which has also been called into question previously. And the estimation of the impact that imperfect heat detection has also assumes the typical cow will be seen in estrus about half an estrous cycle following the end of the VWP. Again, as we discussed above, this is unlikely to occur across the board. But, though they are imperfect, and we should always be cognizant of how differences in our client herds can play havoc with these assumptions, they make for useful and intuitive benchmarking indexes.

Waste Days. This is a simple measure of the total losses resulting from reproductive inefficiency. It is calculated by simply subtracting the herd's goal for days in milk at conception from the herd's *average days open*. For instance, if the herd desired a 12.5-month *calving interval*, then the goal for days open would be 100 ([12.5 × 30.4] − 280 = 100). Should the herd's actual reported *average days open* be 147, then the waste days would be as follows:

$$\text{Waste days} = \textit{Average days open} - \text{Goal days open} = 147 - 100 = 47$$

The waste days for this herd, then, is 47. In and of itself, this makes for a simple measure of reproductive efficiency to follow over time. But more can be done with a little more calculation.

CAVEATS. There are no real problems with the previous calculation beyond the question of whether using an average for *average days open* is appropriate.

Days Lost Because Of Conception Failure. This calculation is intended to give the analyst an idea of the proportional contribution of conception failure to overall days lost resulting from failure on the breeding side of the reproductive process. It assumes that, in a perfect world, a 100% efficiency in breeding is attainable. Therefore any breedings beyond 1.0 indicates a failure. For example, if a herd had an *average days open* of 147 and a *services/pregnancy, pregnant*

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cows of 2.22, the days lost resulting from failure of conception (DL_C) would be calculated as follows:

$$DL_C = (\textit{Services/pregnancy, pregnant cows} - 1) \times 21$$
$$DL_C = (2.22 - 1) \times 21$$
$$DL_C = 26$$

CAVEATS. The true figure for days lost resulting from conception failure is likely lower, since this index assumes 100% accuracy in estrus detection. That is, it assumes all cows bred were actually in estrus. The analyst knows this is not the case, so he or she is probably "blaming" some of the extra open days inappropriately on conception problems. In addition, as mentioned previously, this index uses a base expectation of a perfect world. Some clients may get tired of always being told they are not perfect; they are also unlikely to be willing to pay you for having a firm grasp of the obvious. We will deal with that soon, but first let us take a look at what we can come up with for days lost resulting from estrus detection errors.

Days Lost Resulting From Estrus Detection Failure. This estimation is aimed at the intensity of estrus detection on a dairy herd. If the above herd also had a VWP of 60, the days lost resulting from estrus detection failure (DL_{ED}) would be derived by the following equation:

$$DL_{ED} = \textit{Average days open} - (VWP + 10) - DL_C$$
$$= 147 - (60 + 10) - 26$$
$$= 51$$

This calculation estimates the time lost resulting from missing heats to be 51 days, or nearly twice that of the loss resulting from conception trouble. Therefore, if the practitioner wanted to help this herd, he or she might want to focus initially in on estrus detection, since it appears to contribute the highest proportion of inefficiency to the herd. Note also that the *average days open* minus the sum of DLED and DLC comes to $147 - (51 + 26) = 70$, which is when the average cow is typically assumed to come into estrus after a VWP of 60 days.

CAVEATS. Again, remember that we said the previous calculation likely overestimated true conception losses. This figure is likely, therefore, an *underestimate* of the true losses resulting from failures in estrus detection. Also, the aspect of the client being held to an impossible standard applies here as well.

Converting "Days Lost . . ." Calculations To Fit With Goals. Remember that the two "days lost . . ." calculations look at losses compared with perfection. A dairy will never be able to live up to them. One way to keep these issues up front with a client, and yet reward the client for reaching a goal, is to compare these figures against the more practical and goal-oriented waste days. The thinking here is that, should a client reach a goal for reproduction, our figures should indicate "zero inefficiency." Such a finding can lend a great deal of motivation to, and build a strong sense of personal satisfaction in, a client. It is explained below.

The process is simple. The consultant first derives the relative percentages of lost days resulting from one aspect of reproductive practices: either conceptions or estrus detection. Then the consultant multiplies this figure against waste days to arrive at the actual loss, relative to a reasonable goal, not relative to an unreasonable expectation of perfection. This figure subtracted from waste days will yield the losses resulting from the other aspect of reproductive practices:

$$\text{Proportion lost days resulting from conception } (PL_C) = DL_C / (DL_C + DL_{ED})$$
$$PL_C = 26 / (26 + 51)$$
$$PL_C = 0.34$$

$$\text{Loss vs goal resulting from conception } (GL_C) = PL_C \times \text{Waste days}$$
$$GL_C = 0.34 \times 47$$
$$GL_C = 16$$

$$\text{Loss vs goal resulting from estrus detection } (GL_{ED}) = \text{Waste days} - GL_C$$
$$GL_{ED} = 47 - 16$$
$$GL_{ED} = 31$$

The relative importance of the loss resulting from problems with estrus detection is still roughly twice that of the loss resulting from conception failure, so we have not given up our ability to identify which of the two seems to contribute most to reproductive inefficiency. Now, however, should the farm reach its goal for *average days open* (100 days), both of the estimated "losses vs goals" calculations will generate values of 0.0, just as they should upon reaching that goal. Pat your client on the back. Buy them a bottle of champagne. Let them be happy. Then set a new tougher goal and start the process all over.

CAVEATS. The problems with the set of calculations presented are the same as for the indexes that went into it. Because the calculation depends on *average days open*—a right-skewed data set—the use of an average can be misleading. The median would be more realistic but is not reported under most records systems.

Measures of Change in Overall Reproductive Performance. A relatively simple means to evaluate whether there are changes in overall reproductive efficiency over the preceding year is approached by creating a comparison of different ways to calculate calving intervals.

Predicted Calving Interval Versus Actual. As mentioned before, the published *calving interval* is largely of historical interest; it yields information on what happened over the past year or more. This is insufficient resolution to be of much value in day-to-day decision making. However, the practitioner can use *calving interval* as part of a process to generate data regarding current operations, specifically whether overall reproductive performance has improved, stagnated, or worsened over the preceding year. This is accomplished by comparing *calving interval* against a calculated *predicted calving interval*. It accomplishes this by indirectly comparing *average days open* to *calving interval*, by transforming *average days open* into the *predicted calving interval*. To do this, simply add the typical cow's gestation length (average = 280 days, range for Holstein = 278 to 282 days) (Youngquist, 1997a) to *average days open*. Divide this by the number of days per month (365/12= 30.4) to get the *predicted calving interval* in months. For example, the *predicted calving interval* for a herd averaging 147 days open would be as follows:

$$\textit{Predicted calving interval} = (\textit{Average days open} + \text{gestation length}) / (\text{Days per month})$$
$$\textit{Predicted calving interval} = (147 + 280)/30.4$$
$$\textit{Predicted calving interval} = 14.0$$

In general, comparison of the *predicted calving interval* with the published *calving interval* will give an analyst insight into progress on the farm. If overall reproductive performance is improving, then the *calving interval* should exceed the *predicted calving interval*; if performance is decreasing, the opposite will occur.

CAVEATS. Culling can impact *predicted calving interval* calculations. The concerns mentioned for *average days open* or *calving interval* also apply to this index.

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MONITORING REPRODUCTIVE PERFORMANCE

Changing General Role of the Veterinarian

From Commodity to Investment

For most of the twentieth century veterinarians responded to their clients' requests for assistance after the client had identified a problem. Most commonly this problem dealt with an individual animal. So, then, did the veterinarian's response. The costs of the problem had to be balanced with the costs of the solution, for veterinarians' activities were in the role of loss minimization. The natural criterion for clients to use in choosing a veterinarian, then, was cost. As a result, many veterinarians concentrated on having the lowest charges they could; their time and effort was a commodity, and all commodities' markets are determined by price. In the 1960s and 1970s, however, a different model emerged for food animal practice: the scheduled services model. At the start these services were primarily focused on reproduction and udder health. Because the veterinarian's activities were aimed at groups of cows, as opposed to strictly focusing on individual animals, the costs of those interventions could be amortized over the group. This lessened the cost pressure somewhat. But at this stage, however, veterinarians were still largely in the role of responding to problems identified by the client; veterinarians were still loss minimizers. By the 1980s, however, production medicine came into its own. Two major differences exist between production medicine and previous practice modalities. First, the veterinarian should be at least as involved in monitoring the herd as the client. Second, the veterinarian acts on herd-level trends by dampening negative trends and promoting positive trends. For production medicine, inputs are affecting numerous animals, and because they largely work through long-term programs, the effect is also long term. The veterinarian is no longer a "loss minimizer" but an "investment" in widely affecting long-term results. This is rarely seen in purest action as in dairy reproduction.

Basic Objectives for Either Seasonal or Nonseasonal Herds

The basic objective of most programs is an average days open of 85 to 120 days (calving interval of 12 to 13 months), although the preceding parts of this chapter should cause the reader to only accept this goal after evaluating what is best for any individual dairy. How this is achieved biologically is the same, irrespective of the breeding plan used in the herd. The breeding plan may be year round with some cows calving every month, as is the case in most North American dairies, or with seasonal or block mating, which is more common in European dairies. In these cases, mating may be concentrated in one part of the year or in two mating periods to catch the flush of pasture growth or to have maximum milk available when incentive prices operate.

The measurement of reproductive efficiency is performed differently for the two management systems. In seasonal or block-mated herds the emphasis in management is on concentrating the mating, and therefore the calving, into as short a season as possible. This may be as short as 6 weeks. It is not possible in these circumstances to watch trends, correct management, and observe results. Everything happens too quickly. In these herds it can be worthwhile to make weekly visits and be on the watch for early warnings, but trends do not really become evident over such short time spans. Therefore the farmer's activity is concentrated into the breeding period with a view to getting as many cows pregnant as possible, using the veterinarian in the periods immediately before and at the end of the breeding period to intervene if estrus or breeding rates are too low or to attempt to concentrate unbred cows into a tight group if the breeding period is too extended.

In a herd bred year round, the veterinarian can observe performance from month to month and recognize trends early, which enables him or her to recommend changes in management and environment and then observe the effects of the changes over the next month or two. The essence of veterinary reproductive services in these herds is a repetitive cycle of monitoring (use of records, observations, and palpation) and intervention.

There is, in addition, a need for veterinary participation in routine herd level evaluation, reproductive examinations and pregnancy confirmation, and laboratory investigations. Veterinarians also have a role to play in preventing loss by abortion, infectious infertility, and dystocia. Their participation in this sort of work generates data that are invaluable in measuring performance and supplying back-up data that may be critical when making a causative diagnosis.

Example of Reproductive Evaluation Using Commercial Dairy Records Analysis Software

Introduction to the Example Herd

The example herd is a 120- to 130-cow dairy in southeastern North Carolina that has been having problems in a number of areas, one of which is reproduction. The herd has been in its current site for decades. It is bred by AI and is a confinement-reared dairy. We will look at some of the records normally available, as well as some software that allows for customized investigations. Finally, we will calculate some of the indexes listed in the previous sections of this chapter.

Dairy Herd Improvement Data

Fig. 7-6 displays the commonly reported reproductive data by DHIA. In Fig. 7-6 it has been excerpted using the PC-DART records software (PCDART 7.0, Dairy Records Management Systems), as PCDART's *Standard Report 801* – Herd Summary – Reproduction. It lists, in order, sections relating to summarizing events of the current breeding herd and the total herd, as well as summaries by service sire, on abortions (evidently not reported by this herd), a dry cow profile, and a 12-month summary. A few items to note from this report:

Reproductive summary of current breeding herd. The first column of the first section of Fig. 7-6 indicates the total breeding herd is 22 animals, equally divided between first lactation, second lactation, and third-plus lactation cows. With only 7 or 8 animals per subgroup, be careful not to consider differences of 10% to 15% as being important; a difference of 1 in 7 is over 14%. Similarly, there are only 18 animals in the *Bred But Not Diagnosed Pregnant* ("Bred But Not Diag. Preg.") group. However, the suggestion from this table is that *days to first service* seems to increase with parity; the older cows are being bred first nearly one estrous cycle period after the first lactation animals. Of course, always be skeptical of such trends when they are established with only two to four animals in each group.

Reproductive summary of total herd. The second section of Fig. 7-6 suggests that 16% of all first services occur *before* the end of the VWP. This suggests the herd management is not using its records effectively; rigorous use of records would prevent such early breedings. In addition, nearly one fourth of the herd is first bred after 100 days in milk, meaning they are at least 40 days beyond the VWP (VWP is shown at upper left of the report). This section does not support the

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REPRODUCTIVE SUMMARY OF CURRENT BREEDING HERD

VWP 60

	Number	Not Bred or Diag. Open			Bred But Not Diag. Preg.				
		Number from VWP to 100 days	Number over 100 days	Number Diag. Open	Number Open fewer than VWP	Number Open VWP to 100 days	Number Open 101 to 130 days	Number Open more than 130 days	Days to first service
1st Lact	7	1	4	2	0	1	0	1	65
2nd Lact	7	2	2	0	0	1	0	2	73
3rd+ Lact	8	2	2	1	0	0	0	4	81
All Lacts	22	5	8	3	0	2	0	7	75

REPRODUCTIVE SUMMARY OF TOTAL HERD

	Days Open at 1st Service			Avg. Days to 1st service	Services per Pregnancy		Projected Minimum		Service or Heat Interval				
	Number Fewer than VWP	Number from VWP to 100 days	Number over 100 days		Preg. Cows	All Cows	Calving Interval	Days Open	Less than 18 Days	18 - 24 Days	25 - 35 Days	36 - 48 Days	More than 48 Days
1st Lact	3	15	5	87	3.8	4.5	19.6	315	1	3	1	12	43
2nd Lact	6	16	12	95	2.9	3.3	16.3	215	0	1	1	14	41
3rd+ Lact	7	31	7	83	2.9	3.1	15.1	178	0	5	4	8	42
All Lacts	16	62	24	88	3.1	3.5	16.6	224	1	9	6	34	126
% of all 1st srvs	16	61	24		Current Actual Calving Interval								

ABORTIONS

	This Month	Past Year
Actual	0	0
Apparent	0	0

SUMMARY BY SERVICE SIRE

Services for Past 12 Months			
Service Number	Number Services	% Successful	Service Sire PTA $
1st srv	88	28	+192
2nd srv	57	36	+205
3rd+ srv	105	16	+195
All srv	250	25	+197

YEARLY REPRODUCTIVE SUMMARY

Date of Test	% Heats Obs.	Number Services	% Successful	Number Confirm Preg.	Number Calving	Total Pregnant Cows
Month Dropped	42	25	4	0	7	70
09/22/1998	38	22	0	2	10	57
10/22/1998	9	6	0	3	12	60
11/20/1998	42	27	4	6	14	67
12/18/1998	48	27	41	0	17	41
01/22/1999	39	29	38	12	13	38
02/23/1999	37	25	16	4	4	53
03/23/1999	48	33	39	13	4	56
04/23/1999	48	35	43	9	4	59
05/20/1999	28	13	15	9	4	57
06/24/1999	48	23	13	14	7	77
07/22/1999	22	6		2	2	85
08/24/1999	15	4		0	7	92
Averages	37	21	25	6	8	62
Totals		250		74	98	

DRY COW PROFILE

	Number Dry Periods	Dry Days	Number Dry Fewer Than 40 Days	Number Dry 40 - 70 Days	Number Dry More Than 70 Days
1st Lact					
2nd Lact	30	57	2	26	2
3rd+ Lact	53	57	2	48	3
All Lacts	83	57	4	74	5

FIG. 7-6 Example of a reproductive summary report from a computer-based records system (PC-DART), which is, itself, an excerpt from the Dairy Herd Improvement Association Herd Summary Report (Report 202). It indicates this example herd has severe reproductive problems, as identified in the text. *VWP*, Voluntary waiting period.

parity-based increase in *days to first service* ("Days Open at 1st Service") suggested in the previous section; here, each parity group has extended time to first breeding. *Services per Pregnancy, Pregnant Cows, ("Services per Pregnancy, Preg. Cows")* in the next set of columns, is elevated for all parity groups, but especially so for first lactation animals. The same is true for the "Services per Pregnancy, All Cows." The projected calving intervals and days open show extremely extended periods. Here it appears that older cows are actually doing better, relatively speaking. The last set of columns addresses *interestrus intervals*. The majority of these intervals are in the 36+-day categories. This suggests either poor estrus detection and/or early embryonic loss.

Dry cow profile. Nearly 90% of the dry periods are in the 40- to 70-day category. Approximately 6% of the dry periods are longer than 70 days. However, the average dry period is 57 days, so it does not appear that those beyond 70 are likely to be much longer than recommended. There is no suggestion, therefore, that this herd is drying off cows that took too long to be bred, and therefore, have elongated dry periods.

Yearly reproductive summary. This herd appears to have an estrus detection problem; its monthly average for *percent heats observed* ("% Heats Obs.") is 37, with a best figure of 48 and a worst of 9. This herd shows that estrus detection is at its best, relatively speaking, in the cooler months of winter and spring, which is typical for the southeast. Note, also, that the "success rate" or *conception rate* for those breedings is quite low (avg = 25; range = 0 to −43). As mentioned previously, it cannot now be determined whether this poor conception rate is due to breeding technique or estrus detection inaccuracy. However, the veterinarian should be

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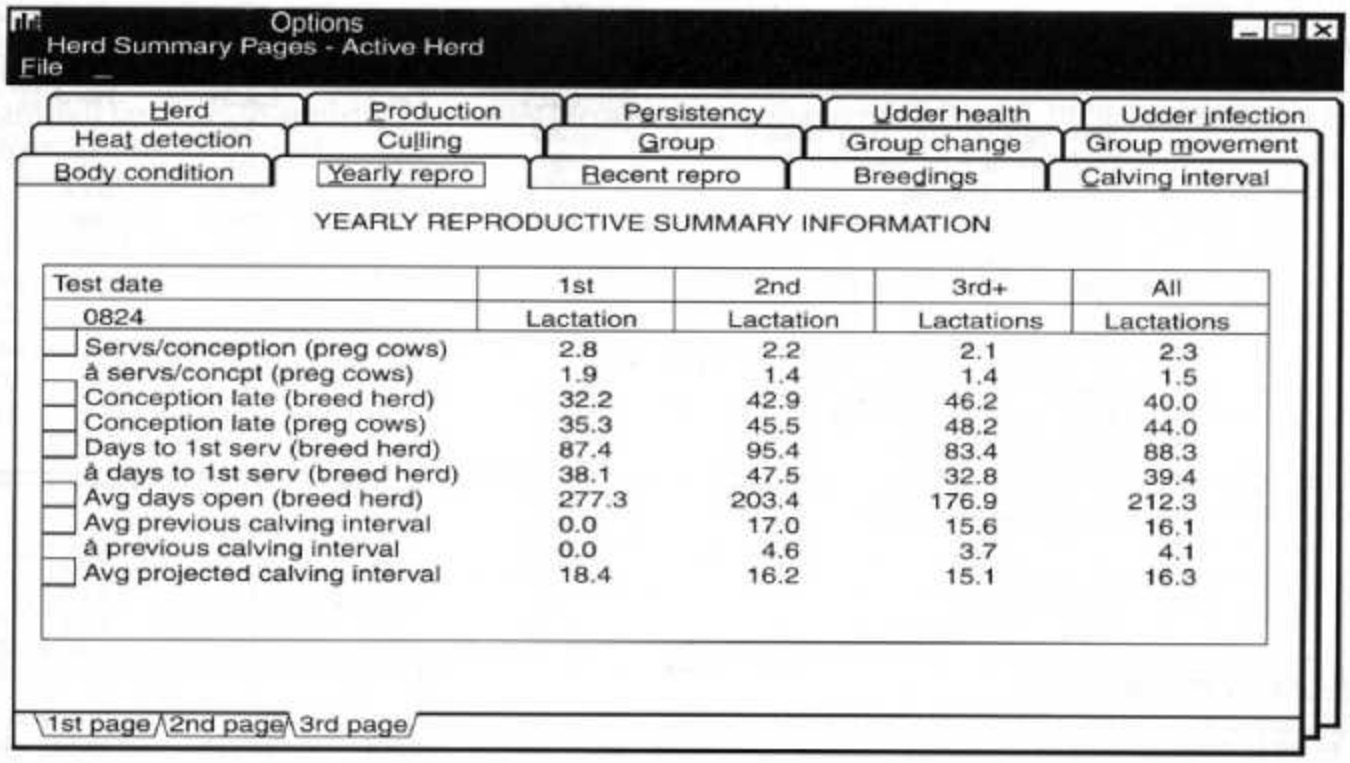

Test date	1st	2nd	3rd+	All
0824	Lactation	Lactation	Lactations	Lactations
Servs/conception (preg cows)	2.8	2.2	2.1	2.3
â servs/concpt (preg cows)	1.9	1.4	1.4	1.5
Conception late (breed herd)	32.2	42.9	46.2	40.0
Conception late (preg cows)	35.3	45.5	48.2	44.0
Days to 1st serv (breed herd)	87.4	95.4	83.4	88.3
â days to 1st serv (breed herd)	38.1	47.5	32.8	39.4
Avg days open (breed herd)	277.3	203.4	176.9	212.3
Avg previous calving interval	0.0	17.0	15.6	16.1
â previous calving interval	0.0	4.6	3.7	4.1
Avg projected calving interval	18.4	16.2	15.1	16.3

FIG. 7-7 Screen capture of Dairy Records Management Systems' CTAP (Current Test-day Analysis Program) from Herd Yearly Reproductive Summary Page for an example dairy. It allows a quick view of several reproductive management indexes. *â*, Standard deviation of index immediately preceding.

concerned with both estrus detection and conception on this dairy.

Evaluation of Fig. 7-6 suggests the herd has extremely long *days open* and *calving interval* as well as extended *days to first service*. In addition, *services per conception* for either all cows or pregnant cows is overly high. The *interestrus interval* data given in the "Service or Heat Interval" section identifies the point that intervals are two or more estrous cycles. Finally, *Days Dry* (or "Dry Days") is not extended, however, the data for *Percent Heats Observed* and *Pregnancy Success* indicate both heat detection and conception could be problems.

Current Test-Day Analysis Program, Herd Summary Pages/Yearly Reproductive Summary Information

This is a report generated by another program in the PC-DART package, CTAP (Current Test-Day Analysis Program), and is displayed in Fig. 7-7. It largely repeats the data from Fig. 7-6, except that it also, as an option, lists the standard deviations (SDs) for several of the indexes. This allows the veterinarian to determine if the use of averages for these indexes is appropriate. The *services per conception, pregnant cows* ("Servs/conception [preg cows]") index shows a standard deviation that is over half the magnitude of the average. This means that a 2 SD distance below any of these figures will go into negative values. This cannot happen in real life, so the only explanation is that these data are highly skewed. Thus the use of averages for *services per conception* is not appropriate. The *Days to First Service* ("Days to first serv [breed herd]") data barely pass the 2 SD test. It appears, then, that these indexes may be nominally distributed normally, at least sufficiently so that averages are credible measures of central tendency. The new data presented by CTAP are the *Average Previous Calving Interval* ("Avg previous calving interval"). It easily passes the 2 SD test. It suggests that calving intervals, by parity group, were poor last year, suggesting that reproduction could be a long-term problem.

Spreadsheet Calculator

Fig. 7-8 is a spreadsheet that calculates reproductive rates and ratios that expand the value of information from the DHIA-based indexes, as defined earlier in the chapter. It makes the calculations for each of the three standard parity groups, as well as on a herd basis. Each of the four "Estrus Detection Measures" suggest estrus detection is only in the upper 20% to upper 30% range. Relative to a goal of 70% to 80%, this is exceptionally poor performance. The "Days Lost Due to Inefficiencies" measures suggest first lactation animals have twice the amount of *waste days* as do the other parity groups, which are themselves losing 50 to 90 days. It appears that 24% to 37% (average, 29%) of those *waste days* is due to conception failure. Hence, estrus detection inefficiency is responsible for two to three times that proportion of *waste days*, with first lactation animals appearing to suffer the worst estrus detection. Finally, it seems that there may be some evidence that things are actually getting better, although only marginally so. Such a result could simply be due to culling effects.

Summary of Findings

The DHIA, CTAP, and spreadsheet analyses all point to severe problems with estrus detection on this herd. Conception rates are also a concern, however, they likely only contribute 25% to 33% as much inefficiency (and, hence, costs or losses) as do estrus detection errors. The worst overall performance appears to be in the first lactation animals.

Further investigations would be warranted. Certainly, the analyst should look at nutrition and body condition to determine if there are contributing difficulties here. In addition, because of the first lactation involvement, the analyst should be interested in determining if facilities are limiting or if the youngstock program is producing poor heifers. With conception rates in question, a review of breeding procedures and techniques is also necessary.

The example provided should not be taken as exhaustive; it is meant only to give the reader a few suggestions in how

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Herd Statistics *From PCDART: Report 801 - Herd Summary - Repro; CTAP Yrly Repro Summary*

	Lac1	Lac2	Lac3+	Herd
Services/Concept., Preg Cows	3.8	2.9	2.9	3.1
Days in Milk First Breeding	87	95	83	88
Interestrus Interval	55.3	56.5	54.4	55.4
Voluntary Waiting Period	60	60	60	60
Average Days Open	315	215	178	224
Previous Calving Interval	–	17.0	16.1	16.6
Taken from Veterinary Examination Lists				
Number Cows for Preg. Check	11	9	17	37
Number Cows Found Pregnant	2	2	3	7
Number Cows not Eligible	0	1	1	2

Herd Goals *Taken from Herd Goals*

Days Open	125	125	125	125
Calving Interval	13.3	13.3	13.3	13.3
Pregnancy Rate at Preg. Check	80%	80%	80%	80%

Calculated Parameters

Estrus Detection Measures	Lac1	Lac2	Lac3+	Herd
1 Pregnancy Rate at Pregnancy Exam	18%	25%	19%	20%
2 Percent Breedable Estrus Events Detected				
Number Breedable Heats	12.7	7.9	6.1	8.3
% Breedable Estrus Events Det'd	30%	37%	47%	37%
3 Breeding Interval Estrus Detection Efficiency				
Breed. Int. Using DIM @ 1st Service	81.4	63.2	50.0	64.8
Efficiency	26%	33%	42%	32%
Breed. Int. Using Vol. Wait. Period	87.5	76.3	56.8	73.3
Efficiency	24%	28%	37%	29%
4 Interestrus Interval Estrus Detection Efficiency	38%	37%	39%	38%

Days Lost Due to Inefficiencies	Lac1	Lac2	Lac3+	Herd
5 Waste Days	190	90	53	99
6 Days Lost via Failure of Conception				
Versus Perfect Performance	59	40	40	44
Versus Goal Performance	46	25	20	28
Percent of Lost Days	24%	28%	37%	29%
7 Days Lost via Failure of Estrus Detection				
Versus Perfect Performance	186	105	68	110
Versus Goal Performance	144	65	33	71
Percent of Lost Days	76%	72%	63%	71%

Historical versus Current Performance	Lac1	Lac2	Lac3+	Herd
8 Predicted Calving Interval versus Previous Calving Interval				
Predicted Calving Interval	19.6	16.3	15.1	16.6
Previous Calving Interval	–	17.0	16.1	16.6
Ratio of Predicted:Actual	NA	0.96 : 1	0.94 : 1	1.00 : 1

FIG. 7-8 Spreadsheet calculator of the enhanced reproductive parameters discussed in the text and derived from the problem herd illustrated in Figs. 7-6 and 7-7.

to interpret and synthesize the information from standard dairy records systems.

FINANCIAL IMPLICATIONS OF REPRODUCTIVE INEFFICIENCY

Concerns and Caveats

The process of estimating the cost of reproductive inefficiency is confounded by many issues (Britt, 1985). Earlier in this chapter we discussed the difficulties in interpreting many of the standard measures of reproduction. Since our measures of financial implications for reproductive performance depend on these indexes, it makes sense that economic estimates of the bottom line impact of a dairy's reproductive successes and failures should also be viewed with a somewhat skeptical eye. For instance, several indexes *(days open, days in milk, days to first breeding)* are skewed so that looking at mean values will be misleading—yet veterinarians often talk about the "cost of an extra open day" without regard to its distribution within a herd. Other indexes predominantly represent historical data (for example, *calving interval*) that may or may not be applicable to today's decisions and may be strongly affected by culling and replacement policies—yet veterinarians often compare calving intervals at one time across herds, and within a single herd across time, without

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considering how it can be confounded. Finally, with differing goals between farms, changeable business structures across dairies, and varied pricing strategies between regions, there are no hard and fast rules in applying economic theory to dairy farm reproductive performance.

Even given the above caveats, some things can be stated. The financial implications of reproductive inefficiency will be based on the biological outcomes of the system, and those outcomes can be described. For instance, in herds that calve year round, the major loss when cows are slow to conceive is lost milk production because the cow spends more time at the end of lactation or as a dry cow. The cost of the lost milk depends on both the price of the milk and the cost to produce it, which vary over time and season and are different for cows at varying levels of production. There is a clear association between poor reproductive performance *(extended days open)* and lowered milk production (Fetrow et al, 1988) when measured as an average per day. The association is probably not entirely causal; managers who do poorly at reproductive management likely do poorly in other management aspects as well. There are other reports, however, that specifically relate selection for high production with increased health care requirements, including reproduction (Gilmore and McDaniel, 1977; Shanks et al, 1981; Young et al, 1985), and with a concomitant potential genetic selection for extended lactation length (Silvia, 1998; Washburn et al, 2000). In seasonally calving herds, small delays in conception may mean that the cow will be culled, so loss per extra day open is an abruptly discontinuous function. Reproductive inefficiency reduces the number of calves born, increases the cost of semen and labor expended, may increase the cost of veterinary service and therapy, and slows genetic progress. As mentioned previously, any consideration of the costs of reproductive inefficiency quickly becomes connected with culling policy and its costs. If cows are culled to improve average reproductive performance, those costs should be assessed properly as reproductive costs, even though often they are not considered.

One last factor that impacts the ability to distill out the financial outcomes of reproductive efficiency is that most of the basic methods of financial analysis, such as partial budgets (see Chapter 2), ignore risk. Although it makes sense that the quicker a cow is bred back, the higher a proportion of her upcoming lactation will be spent in the higher producing early stages. She will also be more quickly facing one of the riskiest periods in her life: the peripartum period. Hence, shortening of the lactation intervals also increases the proportion of a cow's lifetime that she is most at risk of disease and injury, not to mention that it also increases the proportion of her life spent as a nonproducing dry cow. Other risks factor into the decisions that determine a cow's overall reproductive success or failure. In the warm climate areas of the world, seasonal heat stress often changes the risk perception, and therefore the decision process, of breeding a cow. For example, the risk of lowered production based on season of calving in the southeastern United States may well overwhelm any general concerns about lactation length (Farin et al, 1994). Failure to consider the risks inherent in reproductive management leaves out important information that molds the decision to breed or to not breed a cow.

As discussed in Chapter 2, our inability to know everything, and our being forced to address uncertain situations, does not excuse us from helping our clients make decisions. Similarly, even though we understand that the measures we use are less than perfect and that many studies will not include every important facet of a problem, we can still make use of the literature in exploring the financial implications of reproductive inefficiency in modern dairies. We simply need to be careful in how we interpret them.

Reproductive Performance and Finances

Some studies have used retrospective data or surveys to investigate the association between reproductive performance and finances (Olds et al, 1979; Jansen et al, 1987; Lemrick et al, 1987). Estimates in the United States for the cost of a day open past some target level (85 to 100 days) have varied: $0.78 (Speicher and Meadows, 1967), $1.00 (Britt and Gaska, 1998), $1.22 (Lemrick et al, 1987), and $2.03 (Lineweaver, 1975, assuming a target of 85 days). There are many problems with all of these estimates. Each estimate includes differing parameters. For example, some include the value of calves, some subtract feed costs, and some factor in culling costs. The exact nature of the herds used to derive these estimates are hard to extrapolate to a specific existing herd, as are the market prices of cattle or milk. Inflation and the time value of money (see Chapter 2) should be factored in, but specific multipliers are impossible to determine or apply to the various aspects of the analysis. Extrapolation to other countries' management systems and economies is probably too dangerous to attempt.

Perhaps the best way to use these types of studies is to estimate the biological effects and leave it to the user to apply the financial evaluation. For example, in a study in the southeastern United States, it was found that an added day open reduced net milk production 4.5 kg in heifers and 8.6 kg in older cows (Olds et al, 1979). Thus at $0.25/kg milk, the loss in milk income per added day open would be $2.15 for older cows.

Spreadsheet/Modeling Estimates

Spreadsheet approaches to estimating the costs of reproductive inefficiencies have been developed (Goodger et al, 1988; Slenning, 1986). Spreadsheets may have varying degrees of complexity, from assigning a cost per day open to calculating income over feed costs for various stages of lactation and the value of lost calves to the complex accounting of financial flows relating to the dairy's reproductive program. Some may include culling costs and costs of therapy, extra labor, and semen. Some deal with all factors as if they were certain, whereas others allow for uncertainty and encourage "what if" investigation.

Spreadsheets have the advantage of allowing ad hoc evaluations using a particular farm's data. They have a potential disadvantage when the analyst allows the number crunching to get ahead of the logic in the spreadsheet. For instance, in reproductive analyses, certain costs such as feed and labor are often allocated on an average per-unit-milk-produced basis, when in reality these inputs show changing ratio input relationships as production increases. In other words, feed efficiency is not fixed—it tends to improve with increased production (see Chapter 2 for review). A system that ignores this point will inappropriately "penalize" higher production with a poor estimate of efficiency.

The most sophisticated approaches to calculating the costs of reproductive inefficiency are simulation modeling and expert systems, which are mathematical systems that project the biological and financial flows on the dairy that result from specified starting conditions of both farm and cow status and management policy (Marsh et al, 1987; Houben, 1995; Plaizier et al, 1997). Other expert systems may focus less on the financial impacts and serve more as diagnostic systems (Levins and Varner, 1987). Although far more robust than other approaches, these models are often difficult to use or are not available for use by the practicing veterinarian.

Financially Reasonable Goal for Reproduction

None of the programs for estimating the costs of reproductive inefficiency is complete, universally applicable, or fully validated. None has gained wide acceptance or practical

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field use. Veterinarians should accept that all such models are just that, models. Simple, easily understood models that achieve the right order of magnitude may be more useful than complex, inaccessible models that are more accurate and less understandable. In general, what is important is a fairly focused sense of magnitude of loss, so that management can compare the magnitude of the costs of intervention with the costs of the problem.

Considering what is known regarding the costs of reproductive inefficiency, the following conclusions for herds that calve year round seem supportable. Having cows conceive very early after calving (less than 50 days) is at least as costly as having delayed conception. The optimum *days open* is probably between 85 and 120 days for most herds. Herds with excellent reproductive management can afford a stricter policy on culling for production and for failure to conceive by a specific date. Poorly managed herds should be more lenient in their culling policies; extensive culling to achieve acceptable herd statistics for reproductive performance is likely to be more expensive than the extended *days open*.

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CHAPTER 8

Culling and Genetic Improvement Programs for Dairy Herds

BRIAN RADKE and GEORGE SHOOK

Potential Role of Culling and Genetic Improvmeent Programs in Herd Health

Dairy producers and veterinarians have intensified their efforts in nutritional management, udder health, reproductive performance, and replacement heifer rearing to improve herd performance and production efficiency. However, there appears to be less recognition of the potential for herd improvement using two other important dairy herd strategies: culling and genetic improvement.

Organizations involved in dairy cattle breeding, such as artificial insemination (AI) centers, animal geneticists, and breed organization centers, have invested heavily and have made significant strides in genetic improvement (Leitch, 1991). Approximately a 1.5% annual rate of improvement in productivity has been attributed strictly to improved genetic potential. On the other hand, there is little doubt that there could be greater implementation and use of these genetic gains.

Traditionally, veterinarians have not become involved in the culling and genetic improvement strategies, even in herds with comprehensive health management programs. Some veterinarians have become familiar with the prominent sires and cow families in particular breeds. This knowledge is useful for client relations and for developing producer confidence. Extension of this knowledge into meaningful definitions of goals for genetic improvement and effective herd culling strategies, however, has been extremely rare.

This chapter consists of two major sections. The first section presents information on culling in dairy herds. The inseparability of a herd's culling strategy and replacement strategy is emphasized. Methods of developing a prospective culling and replacement strategy based on economic merit are described. In the second section, the basic principles of genetic evaluation and improvement programs are presented. Proposed methods by which veterinarians can incorporate genetic improvement into health management programs are also outlined.

CULLING AND REPLACEMENT STRATEGIES FOR DAIRY HERDS

Culling describes the removal of a cow from a herd because of sale, slaughter, or death. An obvious, but often overlooked, issue in culling is that for a given herd size, the number of replacements determines the number of cows culled. That is, if herd size remains constant, an animal in the herd must be culled for every heifer that enters. The increasing of cow longevity is receiving increased attention in the dairy industry. But longevity cannot be increased without decreasing the number of cows culled, which reduces the requisite number of replacements necessitating the sale (or reduced purchases) of replacement heifers. These points highlight the interdependent nature of a herd's culling strategy and replacement strategy. The commercial availability of sexed semen, with its ability to catapult annual culling and replacement rates well above 80%, will highlight the interdependency. This interdependency is more fundamental than merely relating animal flows into and out of a herd. Culling and replacement decisions are inseparable because, by definition, they involve the comparison of the animal currently in the herd with a potential replacement. Because of their inseparability, the two strategies should be considered a single strategy—the herd culling and replacement strategy.

This section deals with the complex issue of culling and replacement in dairy herds. An economic rather than a biological approach to culling and replacements is used. That is, the cow is not generally culled because she is no longer able to produce or is not profitable, but because a replacement is expected to be more profitable. While profit maximization does not drive every decision, economics usually plays some role in decision making. If nothing else, the profit foregone by not making the most profitable decision is usually of interest to the decision maker. Although the emphasis is on economics, biological factors are important too. Disease is an important factor in animal profitability, and animal welfare concerns may become increasingly important in dairy cow culling and replacement programs. Although the emphasis is on profit maximization, the strategies can be modified easily to maximize other objectives. For example, if the herd objective is to maximize milk production or genetic improvement instead of maximizing herd profit, the principles of animal replacement can be applied to these alternative objectives.

The complexity of the herd culling and replacement strategy is contributed to by its high level of integration with a number of other areas of dairy enterprise management. For example, the culling and replacement policies have direct implications for udder health, disease control and treatment, reproductive management, and replacement heifer programs. Opportunities exist to increase herd profit through an improved culling and replacement strategy. Such a strategy is easy to implement and adapt—the greatest obstacle may be in altering the industry's assumptions and beliefs about culling practices.

The purpose of this section is to provide the information necessary to develop culling and replacement strategies that can be implemented and are profitable. First, the principles of culling and replacement decisions are reviewed and considered. Although it is not possible to directly apply these

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principles to actual decision making, an understanding of the principles is necessary in customizing a herd's culling and replacement strategy. With the aid of computer models, these principles have been used to produce two tools, culling guidelines and a range of target culling rates, which are useful in developing culling strategy. Each tool is considered in turn, including discussion of the various measures of culling. The target range of culling rates does not aid in identifying which cows to cull, therefore the reasons and risk factors for culling and how to interpret this information is presented. The decision about how many cows will be culled dictates the number of replacements required. If there are more replacement heifers than required, a method of heifer selection is required. Then the risk and return from culling and replacement strategies is considered, followed by material on customizing the strategy for a particular herd. This section concludes with the implications of culling and replacement strategies for herd health programs and methods of estimating the culling component of the cost of disease.

PRINCIPLES OF A DAIRY HERD CULLING AND REPLACEMENT STRATEGY

In principle, the herd culling and replacement strategy for a dairy herd consists of the following two steps: (1) identify which cows to cull and which replacements will enter the herd to maximize herd profit, and (2) determine when to actually sell the cows that have been identified for culling. The decision in the second step is relatively straightforward and simple—a cow identified for culling is culled when either limitations in herd resources forces her sale or she is no longer profitable. Examples of limitations in herd resources include an excess of cows for the herd's human or physical resources (e.g., number of stalls, milking parlor capacity) or, in the case of herds operating under a supply managed system, an excess of milk for the herd's quota holdings. A cow designated for culling is no longer profitable when her milk revenue is less than her variable cost of milk production.

A potential role for the veterinarian in the second step of when to sell the cull cows is to incorporate animal welfare concerns into the decision process. That is, consideration of the animal's welfare may lead to her sale earlier or later than would otherwise occur if her welfare was overlooked. In addition, the veterinarian can advise producers about the marketing channel (e.g., livestock auction, direct shipment to slaughter facility, emergency on-farm slaughter, euthanasia) most appropriate given the animal's clinical state.

In contrast to the relative simplicity of assessing when to sell the cows designated for culling, a method of making the more important decisions of step one is not as obvious. Fortunately, standard capital budgeting replacement models provide the principle of how to assess and compare animals' profitability. The *general decision rule* in capital budgeting, customized to culling, is to replace the current asset (i.e., cow) with a replacement (i.e., heifer) if the heifer's expected profit per lactation, averaged over her life, is greater than the expected profit from the cow's next lactation and is greater than the expected average (time-valued) profits from the cow's subsequent lactations. Thus *the replacement decision rule is to replace a cow with a heifer if the heifer is expected to be more profitable.* As explained below, it is not possible to apply this decision rule in making actual cow replacement decisions. However, a good understanding of the principles of cow replacement decisions and the decision rule is important in customizing a herd's culling and replacement strategy.

The decision rule is difficult to apply directly to cows and the potential replacement heifers because of the extraordinary predictive power required. Application requires predicting the future profits of the animals. Furthermore, to properly incorporate the process of genetic improvement, these predictions are required for all potential future herd replacements. To predict an animal's future profit requires predicting her biological performance such as future milk production, which, at a minimum, requires predicting her future reproductive performance. While onerous, these biological predictions are possible through the use of statistical techniques, such as survival analysis. However, it is important to appreciate that predicting a potential replacement heifer's expected profit per lactation, averaged over her life, also requires predicting the length of her life or when she will be culled. Thus, by applying the decision rule above, she will be culled when the expected profit from her next lactation is less than her potential replacement's expected profit per lactation (again averaged over the potential replacement's life). In other words, to know the current replacement heifer's expected average profit per lactation requires knowing the culling decision of all her potential replacements. In addition, presumably, if the culling decisions of potential future replacements were known, then the culling decision of the current cow and replacement heifer would also be known and this exercise would be unnecessary. Thus step one is complicated. The folly of trying to circumvent this complicated, but necessary, approach by using simple cow versus heifer comparisons in making culling decisions has been examined (Radke and Lloyd, 2000).

Solution techniques for the complex, capital budgeting replacement issues just mentioned are available and have been applied to the issue of culling and replacement strategies to maximize producer profit. These models are intended to test the impact of various culling decision strategies on the profitability of a dairy enterprise. Briefly, the two broad categories of computer-based solution techniques are simulation (Allaire and Cunningham, 1980; Allaire, 1981; Congleton, 1988; Marsh et al, 1987; Dijkhuizen and Stelwagen, 1988) and optimization models (Rogers et al, 1988a; Dijkhuizen et al, 1985; Van Arendonk and Dijkhuizen, 1985; Bauer et al, 1993). Both techniques require simulating the animals and management of a dairy herd for decades. The models simulate the biological performance of the animals, including their milk production, health events, and reproductive performance. The management decisions simulated include breeding and culling decisions for each animal. The economic performance of the animals is also included. The simulation models can be used to compare different culling strategies. But the conclusions drawn from the comparisons should be tempered with the realization that the best strategy is only relative to those considered. That is, alternative strategies may exist that are superior to those considered. In contrast the optimization technique leads to the optimum culling policy (i.e., the culling policy that maximizes herd profit) for the conditions modeled. The optimization models generally use numeric stochastic dynamic programming to apply the capital budgeting decision rule to each animal and all potential replacements of the herd for decades. The models included moderate values of estrus detection and conception rates, and culled cows were sold for meat (not dairy) purposes. In addition, sensitivity analysis is used to investigate variations in the input assumptions on the economic outcome.

The complex computer optimization models have been recommended to develop culling policies specific to a given situation rather than applying general guidelines (McCullough and DeLorenzo, 1996). This recommendation was based on the finding that simultaneously varying a number of the model inputs resulted in meaningful changes to the optimal policies. The lack of availability of the models and expertise required to customize and operate the models limits the practicality of the recommendation. In addition, the

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data collection and analysis required to fully customize a model for a specific herd could be quite burdensome. Similar to other areas of herd management, culling recommendations that are herd or animal specific are not currently feasible. However, these models have led to two tools, culling guidelines and a range of target culling rates, which are useful in developing a culling strategy. Each of these are presented including consideration of the various measures of culling. The discerning reader will recognize that despite the earlier discussion of the necessity of simultaneously comparing the cow and the replacement, the emphasis will be first on cow culling, followed by consideration of replacement heifer selection. In order to implement a culling and replacement strategy, it is necessary to disengage into a culling strategy followed by a replacement selection strategy. However, despite appearances, the interdependency is maintained because, in generating the two tools, the computer models simultaneously considered the cows and the replacements.

CULLING GUIDELINES

Insemination guidelines are available for Dutch and U.S. dairy herds (Tables 8-1 and 8-2). A simplified guideline for dairy herds has also been produced (Table 8-3). These guidelines indicate the minimum level of milk production to start and continue breeding individual cows. Cows not inseminated are designated for culling. The level of milk production is relative to the herd average production and is expressed on an age-corrected basis. Thus, for example, production level comparisons would be based on mature equivalents or breed class averages for the United States and Canada, respectively. Cows at the minimum level of milk production are expected to be equally profitable as the average replacement heifer. Cows at greater than the minimum production level are expected to be more profitable than the average replacement. The Dutch Dairy Herd Improvement Association (DHIA) has made insemination guidelines available to producers to aid their individual cow insemination and replacement decisions (Dohoo and Dijkhuizen, 1993).

The guidelines suggest that some low-producing animals should never be bred, whereas only moderate levels of

TABLE 8-1

*Critical Production Level Below Which Further Attempts at Breeding Are Not Economically Justified**

	Calving Interval (Days)				
	365	405	445	485	525
	Days Open at Decision (Days)				
Lactation Number					
1	86	88	90	92	95
2	86	88	90	93	95
3	88	90	92	95	98
4	91	93	95	98	101
5	92	94	97	99	102
7	97	99	103	105	109
10	111	113	117	120	124

From Dijkhuizen AA, Renkema JA, Stelwagen J, et al: *Prev Vet Med* 3:265-276, 1985.

*For dairy conditions in the Netherlands, this table shows the effect of increasing parity, and increasing days open on the minimum production level (as a percentage of the herd average) required to economically justify breeding a cow. For example, a third-lactation cow at 125 days in milk needs to have only 90% of the herd average milk production to warrant breeding. On the other hand, a seventh-lactation cow at 205 days open should not be bred at less than 105% of herd average.

TABLE 8-2

Production Level (Percent of Herd 305 ME) Below Which Insemination Would Not Be Optimum by Parity

	Month of Lactation		
Parity	3	5	7
1	78	82	86
2	78	82	86
3	78	82	90
4	82	86	90
5	86	90	94
6	90	94	102
7	94	98	106
8	98	106	106
9	106	110	118
10	110	118	126
11	122	126	—
12	—	—	—

From Rogers GW, Van Arendonk JAM, McDaniel BT: *J Dairy Sci* 71:3453-3462, 1988.

Note that higher milk production is needed to offset delayed insemination because of lower profit associated with prolonged calving intervals. With increasing age, higher production is needed to counteract the increased risk of culling and ensure the cow is profitable relative to the genetically improved replacement heifer.

TABLE 8-3

Guidelines for Breeding Cows According to Productive Capacity

Production (Percent of Herd Average)	Breeding Strategy
Less than 80	Do not breed
80 to 90	Cease breeding at 160 days
Greater than 90	Cease breeding at 240 days

Dohoo IR, Dijkhuizen AA: *Comp Cont Educ Pract Vet* 15:515-520, 1993.

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production are required to economically justify continued insemination. For example, under Dutch conditions, it is profitable to breed a first lactation animal in her seventh month of lactation if her age-corrected milk production is at least 92% of the herd average (Table 8-1). Premature cessation of breeding this animal, causing her culling and replacement, leads to decreased profit. Also, it may be economically justifiable to persist in breeding cows much later into lactation than is often considered feasible in North America (Dohoo and Dijkhuizen, 1993). These guidelines suggest North American producers have made some premature culling decisions leading to the unnecessary culling of some animals. This led to decreased herd profit because of higher than optimum culling rates.

The simplified guidelines presented in Table 8-3 have been compared with insemination policies of a fixed cutoff point (e.g., no breeding 160 days after calving) that ignored the cows' production. These comparisons were conducted with variable reproductive performance and evaluated under U.S. (Marsh et al, 1987) and Dutch conditions (Dijkhuizen and Stelwagen, 1988). Generally, the simplified guidelines presented in Table 8-3 provide greater economic returns than the more restrictive fixed cutoff point policies.

TARGET CULLING RATE RANGE

Only some of the literature on optimum culling rates provided insemination guidelines. In contrast, it was routine for each study to report some measure of the culling rate that maximized producer profit. The simulation studies would also commonly compare optimum and nonoptimum culling rates and their effects on the economic and biological performance of the herd. There is a general consensus that culling rates of 20% to 30% maximize producer profit under the economic and production conditions commonly found throughout a number of dairy-producing countries (Radke and Lloyd, 2000). An exception is the culling rate in the range of 40%, which is considered optimum in the southern United States because of the effects of heat stress on production and reproduction (DeLorenzo et al, 1992). In the absence of heat stress, the optimum culling rate in the United States is 25% (Rogers et al, 1988a).

It is surprisingly difficult to apply these target culling rates to individual farms for two reasons. First, varying measures of culling are reported in the dairy industry, and although these measures are related, it is not necessarily easy or even possible to convert one measure to another. The second, and likely more important, reason is the lack of standard definitions for these rates, which is a problem exasperated by the failure of many authors to report their method of calculation. As a result, a great onus is placed on the reader of the culling rate literature to ensure apples are not being compared to oranges, as frequently happens.

Calculating Culling and Herd Turnover Rates

There are two common methods of calculating the culling rate. These calculations are limited to animals that have calved at least once. The method adopted here is that *culling rate equals the number of animals culled per year divided by the average herd size*. Although the average herd size for a year can be calculated by averaging the cow inventory at the beginning and end of the year, the use of more frequent measures of herd size is preferred because of fluctuations in herd size. For example, calculating the average by including the herd size in each of the 12 months is more accurate than considering only the size at the beginning and end of the year. Another common method of calculating the rate at which cows leave the herd is dividing the number of animals culled per year by the total number of animals that were ever in the herd in that year. In other words, the denominator of the second calculation, which we call the *herd turnover rate*, is the sum of the average herd size and the number of cows culled. The first method is adopted, not only for its intuitive appeal, but also because it is more epidemiologically accurate. The epidemiological definition of culling rate is the number of animals culled per unit of animal time at risk. Therefore the denominator used in the calculation should reflect the number of animal years the animals were at risk of being culled. The herd turnover approach of using all the cows that were in the herd at any time in the year overestimates this animal time at risk because the culled cows and their replacements were in the herd only part of the year. The herd turnover approach counts a cow and her replacement as each being at risk for the entire year, whereas the culling rate calculation recognizes that, between the two animals, there was only a single year of cow risk for culling.

For example, consider a dairy herd that over the course of a year averages 100 cows and culls 40 cows. Using the above definitions the culling rate is 40% (40/100) and the turnover rate is 28.6% (40/[100 + 40]). Using the above calculations, a 40% culling rate is equivalent to a herd turnover rate of 28.6%.

The literature occasionally refers to culling risk instead of culling rate (i.e., a culling risk of 24%). Technically the culling rate is not a rate because the animals' time at risk has not been calculated with sufficient accuracy. (The calculation of animals' time at risk in terms of days rather than months or years would help alleviate this concern.) *Risk* (i.e., culling risk or, alternatively, culling risk rate) is the term used when the measurement of time at risk is relatively crude. However, because the term culling rate is so entrenched in the culling vernacular, we will continue to use it rather than the preferable terms of culling risk or culling risk rate.

Much more important than the method of calculating the culling rate is ensuring that rates being compared have been consistently calculated. For example, in a survey of 50 dairy herds in England, an average total annual culling rate of 23.8% was reported (Esslemont and Kossaibati, 1997). It appears the average culling rate is well within the target range. However, the reasons for culling 6336 animals were collected from the records of 26,644 animals that calved. This implies the 6336 culled animals are included in the 26,644 animals. Thus with the above definitions, the average culling rate is 31.2% (6336/[26,644 − 6336]) and the herd turnover rate is 23.8% (6336/26,644).

Care is required in comparing the culling rate of herds undergoing expansion with the literature's optimum culling rates, which are for herds of constant size. The mere act of expansion can lead to a lower culling rate than if the herd had maintained a constant size. For example, suppose a 100-cow herd expanded internally to 110 cows in 1 year, and during this year the herd had a 37% culling rate. To achieve a 37% culling rate the herd must have sold 39 cows (0.37 × [{100 + 110}/2]). Thus 39 heifers must have entered the herd just to maintain an average herd size of 105 cows. In addition, 10 more heifers must have entered the herd to permit the internal expansion from 100 to 110 cows. The herd of 100 cows must have actually calved 49 heifers. If the herd had not expanded, its culling rate would have been 49%. Similarly, the veterinarian would expect that once the herd stops internal expansion, the culling rate should return to 49%.

Finally, extra care must be taken in the assessment of culling rates averaged across herds. These averages represent the mean of a distribution of individual herd culling rates. In the example from England, at first glance the average 31.2% culling rate in the herds may not appear problematic

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because the rate is just slightly higher than the maximum of the target range of culling rates. But the distribution of individual herd culling rates is likely symmetrical (i.e., equal number of herds with culling rates above and below the mean culling rate), and thus over half the herds in the study have culling rates higher than the optimum range. This assessment of culling rates is much different than that at first glance.

The culling rate is the preferred measure for monitoring culling in dairy herds. It is easily understood, easy to calculate with commonly available dairy herd records, easy to compare with the literature, and, relative to some of the other measures that are presented below, stable.

Survey of Culling Rates

Average dairy industry culling rates from the last decade for various geographical areas are listed in Table 8-4. This table should be interpreted as a broad picture of the culling practices of the dairy industry as represented by a number of dairy-producing regions of the world. Care must be taken in interpreting the results from any single study and comparing them with others because the methodologies vary greatly. For example, the Australian study was based on only eight herds, so caution is required in extrapolating this result to a larger population. (In contrast, the other studies had a minimum of 50 herds.) In addition, the time frames of the studies ranged from a single year to over a decade. For example, the Canadian study revealed that the annual industry average culling rate ranged from 35% to 38% in the span of 5 years and resulted in the 5-year average of 36% reported in Table 8-4 (Durr et al, 1997a). The study discusses reasons for yearly fluctuations in industry average culling rates. Another difference among the studies was the culling reasons considered. For example, in contrast to the other studies, cows sold for dairy purposes (i.e., exported, sold for dairy purposes or rented) were excluded from the Quebec study (Durr et al, 1997a).

As a broad view of the culling practices of some major dairying regions of the globe, Table 8-4 presents a surprisingly consistent picture. The average culling rates range from 26% in Australia to 36% in areas of North America. The average culling rates of the majority of regions have culling rates above the target range. This suggests dairy producers in a number of areas may be able to profit from altering their current culling and replacement strategies in favor of a lower culling and replacement rate. Application of the earlier warning about interpreting industry average culling rates illustrates the diversity of current culling practices. For example, individual herd culling rates of one study ranged from 13.5% to 49.0%, with an average of 31.5% (Esslemont and Kossaibati, 1997). Similarly, another study with an average culling rate of 28.4%, had an interquartile range of 12% to 54% (Whitaker et al, 2000). These broad ranges around the averages suggest every region has producers with culling rates greatly exceeding the target range of culling rates and therefore the opportunity to increase profit by reducing their rates.

Culling rate is a crude measure of the culling practices of a herd because it is an average for the entire herd. For example, two herds with the same average culling rate can have different age distributions because of differences in the marginal culling rates for each lactation or age of cow. In addition, presumably, the different age distributions will translate into varying profitability. *Herd composition* based on age or parity is occasionally used in the dairy industry (Table 8-5). There are no published suggested herd compositions to maximize herd profit, and if there were, they would likely be difficult to replicate. Although there are no suggested age distributions, the culling guidelines imply 15% to 20% of first-lactation cows should be culled (Dohoo and Dijkhuizen, 1993). The percentage of the herd as first calf heifers can be a useful quick method of gauging the culling rate.

Percentage of First Lactation Animals in the Herd and Culling Rate

Great care must be exercised when using the percentage of first lactation animals in a herd to evaluate the culling rate. This measure of culling can vary widely over time because of

TABLE 8-4

Survey of Dairy Herd Culling Rates

Authors	Geographical Area	Average Culling Rate
Jones et al (1995)	New York, USA	36.0%
Esslemont and Kossaibati (1997)	England	31.2%*
Durr et al (1997a)	Quebec, Canada	36.0%†
Seegers et al (1998b)	Western France	32.3%
Stevenson and Lean (1998a)	New South Wales, Australia	26%
Whitaker et al (2000)	Southern England	28.4%‡
Dohoo and Dijkhuizen (1993)	North America	35%
Rajala-Schultz and Gröhn (1999a)	Finland	31.6%
Smith et al (2000)	Northeastern USA	35.1%
	Mideastern USA	36.3%
	Southeastern USA	34.5%

*Reported as a 23.8% culling rate which according to the definitions used in the text is the herd turnover rate.
†Underestimates actual replacement rate because cows sold for dairy purposes (i.e., exported, sold for dairy purposes, or rented) have not been included.
‡Reported as a 22.1% culling rate, which, according to the definitions used in the text, is the herd turnover rate.

TABLE 8-5

Composition of Quebec Holstein Herds

Parity	Percent
1	33.4
2	24.2
3	17.1
4	11.4
5	7.0
6	3.9
7	1.9
8	1.1

Durr JW, Monardes HG, Cue RI, Philpot IC: *Can J Anim Sci* 77:593-600, 1997.

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changing population dynamics in the heifer and cow populations. For example, unequal distribution of heifer calvings over time, changes in the number of first lactation animals culled, and changes in herd size can all markedly affect the monthly percentage of first lactation animals in the herd. Many DHIAs routinely report the percentage of the herd that is first lactation animals. Because of the potentially wide variation, use of this measure from a single point in time is not appropriate; thus the measure can be misleading. Rather, consideration of the herd's percentage of first lactation animals over some period (e.g., the last 12 months) is a more appropriate measure of the culling rate.

The usefulness of the percentage of first lactation animals in the herd as a measure of the culling rate arises from the vast majority (if not all) of replacements being first-calf heifers. Therefore the percentage of first-calf heifers in the herd, corrected for the calving interval, provides a minimum estimate of the number of animals culled from the herd in the last year. For example, in reporting the average culling rate of Quebec Holstein herds, Durr et al (1997a) stated that, on average, the herds consisted of 33.4% first parity animals. If a herd had maintained a constant size, at least 33.4% of the herd must have been culled in order for the herd to consist of 33.4% first calf heifers. But care is needed in assessing the time span over which this culling has occurred. The average calving interval for these first lactation animals is 12.9 months (390 days) (Durr et al, 1997a). After calving, a first-calf heifer on average remains a first-calf heifer for 12.9 months. Thus culling 33.4% of the herd occurred over the last 12.9 months or 1.07 years, and the annual culling rate for the herd is at least 31.2% (33.4%/1.07). This is the minimum herd culling rate because the first-calf heifers that were culled have not been included in this rate. To understand this, consider a herd that has 33.4% first-calf heifers. If one of the first-calf heifers is culled and replaced with another first-calf heifer, neither the number of animals in the herd nor the number of first-calf heifers has changed. Although a first-calf heifer was culled, the herd still consists of 33.4% first-calf heifers. The actual culling rate can be estimated by dividing the minimum culling rate by 1 minus the (marginal) culling rate of first-calf heifers. From the Durr (1997a) study, roughly 25% of the Quebec first-calf heifers were culled, so an estimate of the herd culling rate is 41.6% (31.2%/[1 − 0.2]). Notice this estimate is greater than the actual average culling rate of 36% reported in Table 8-4. The inaccuracy of the rate based on the percentage of first-calf heifers is due to the variable population dynamics warned of earlier. The percentage of first-calf heifers is perhaps most useful as a quick method of confirming a herd's reported culling rate. For example, if Durr et al (1997a) had reported a herd culling rate of 24% and the herd consisted of 33.4% first-calf heifers, an inconsistency is immediately apparent and further investigation of the culling rate is warranted. A common reason for the percentage of first lactation animals consistently exceeding the herd's reported culling rate by a large amount is the reported culling rate is actually the herd turnover rate.

Length of Cow's Life and Culling Rate

Several culling measures use the length of the average cow's life in a dairy herd. Longevity considers the cow's age at culling. Productive life or herdlife is the length of time from first calving to culling. Thus productive life or herdlife is equal to longevity less the average age at first calving. These measures are variably expressed in the units of months, years, or lactations.

If productive life or herdlife is expressed in years, the culling rate is equal to 1 divided by the herdlife (Durr et al, 1997a). For example, in the Quebec study the overall productive life was 33.1 months for owner sampler herds and 32.97 months for official herds, and the respective culling rates per year were 36.22% and 36.40% (Durr et al, 1997a). If productive life or herdlife has the units of lactations, the analyst must, before calculating the culling rate, convert the units to years through multiplication with the average calving interval measured in years.

Similar to culling rate, herdlife is an average for the herd. Therefore the previous comments about culling rates—such as two herds with the same culling rates, having different age distributions and thus profitability—are just as applicable to herdlife as a culling measure. Measures of longevity are frequently reported monthly by dairy herd improvement associations. Similar to the measure of percentage of first lactation animals in the herd, longevity measures will vary from month to month, although the variation is not as extreme.

CULLING REASONS

A target culling rate assists in the determination of how many cows should be culled but not which cows should be culled. A large literature base describes dairy cattle culling practices, especially the reasons and risk factors for culling. But caution is required in interpreting this literature for a few reasons. A consistent system is lacking for assigning the reasons dairy cows are culled. General agreement does not exist about which reasons should be considered (Table 8-6). Misclassification also occurs because a culled cow typically can be attributed to only a single reason. For example, cows that are poor producers because of chronic subclinical mastitis might be classified as a low production cull or a mastitis cull. A low producer that has not conceived after one or two inseminations may be classified as a reproductive cull (because the producer is less willing to invest time, semen, and effort on a low-producing cow) or as a low-production cull. Another common example of unclear classification of culling reason involves cows with significant lameness. Such cows often have an increased risk of developing mastitis, reduced chance of being observed in standing estrus, reduced feed intake leading to lower milk production, and poor body condition. In fact, the cause of the lameness may have originally been improper provision of fiber in the cow's diet. When this cow is culled, should the reason for culling be attributed to low production, reproduction, mastitis, foot and leg problem, or a miscellaneous reason?

Furthermore, the literature describes industry practices for better or worse, so care is required when this information is used to make recommendations. For example, reproduction is generally one of the more commonly cited reasons for culling. Based on this finding, recommendations are frequently made to focus effort on reproductive management to reduce this culling. But because reproductive performance is a critical and challenging control point in cow profitability, its commonness as a culling reason is *expected*—it would be surprising if reproduction were *not* a common reason. If the producer is interested in profit, these interventions in reproductive management should be undertaken only if they are profitable. Reproduction is a critical element in cow profitability, so some interventions will be profitable, but there is a level of reproductive performance at which the returns from further improvement are insufficient to cover the associated costs. Perhaps the recommendation's concentration on reproductive management is misguided; maybe the problem is not the reproductive management but the decision to cull these animals. As described in the "Culling Guidelines" section, it appears that the decision to stop breeding animals and cull them (likely as reproductive culls) routinely occurs earlier than is economically optimal and leads to decreased

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TABLE 8-6

Reasons Cows Are Culled (Percent of Total Culls)

Reason	Average*	Source of Data: Southeast U.S. (DRPC Raleigh, 1986)†	Canada (Dohoo and Martin, 1984a)	Canada (Westell et al, 1982)	Ohio (Allaire et al, 1977)	New York (Van Vleck and Norman, 1972)	New York (O'Bleness and Van Vleck, 1962)‡	Pennsylvania (White and Nichols, 1965)
VOLUNTARY REASONS								
Dairy sales	13.7	8.8	20.3	32.5	10.4	—	14.3	9.7
Low production	25.4	23.5	25.4	16.6	16.1	32	27.2	36.8
Total voluntary	39.1	32.3	45.7	49.1	26.5	32	41.5	46.5
INVOLUNTARY REASONS								
Reproduction	22.9	23.5	17.1	25.5	34.9	27	16.8	15.8
Mastitis, udder	15.0	11.8	15.1	7.8	14.7	22	14.5	19.2
Disease, injury	10.4	17.6	—	10.2	11.5	8	20.0	5.2
Death	3.3	11.8	7.9	—	—	—	0.6	2.9
Feet and legs	1.8	2.9	5.0	1.8	—	—	2.9	—
Temperament	0.2	—	0.9	0.5	—	—	—	—
Miscellaneous	7.3	—	8.3	5.2	12.8	11	3.4	10.4
Total involuntary	60.9	67.6	54.3	51.0	73.9	68	58.3	53.5

From Fetrow J: *Proc Am Assoc Bov Pract* 20:102-107, 1988.

*Average of the seven studies reported, calculated as a percentage of the total culls.

†From Ken Butcher, personal communication: Dairy Records Processing Center, Raleigh, N.C., 1986. In Fetrow J: *Proc Am Assoc Bov Pract* 20:102-107, 1988.

‡From O'Bleness GV, Van Vleck LD: *J Dairy Sci* 45:1087-1093, 1962. In Fetrow, J: *Proc Am Assoc Bov Pract* 20:102-107, 1988.

herd profit. Then the high reproductive culling rate (and the effect of reproduction on the risk of being culled) might simply be a reflection of the culling criteria for the industry. The reproductive culling rate could be reduced simply by continuing to breed these animals longer, as suggested by the culling guides. This would reduce the reproductive culling without any intervention in reproductive management.

Reasons and risks for culling, and therefore the literature analyzing this industry data, are highly predicated on culling decision making. That is, the literature on culling reasons or risks of culling reflect what is observed (i.e., the factors that farmers consider when they make their culling decisions). This literature does not necessarily indicate the optimum way of culling cows (Rajala-Schultz and Gröhn, 1999a). However, the optimum culling rate literature suggests this decision making could be improved. It is unclear whether the relationships and conclusions in the current literature would still be applicable if the decision-making criteria changed.

The suggestion that culling decisions could be improved does not imply that producers are not correctly identifying which cows to cull. Rather it may be a reflection of the higher than optimum culling rate. As explained earlier, in the assessment of which cows to cull, ideally only those cows that are less profitable than a replacement heifer would be culled. This method leads to the correct culling decisions for each cow and, as a result, produces the optimum culling rate. But the comparison of each replacement with each cow is difficult and would be cumbersome in making the tactical day-to-day decisions of which cows to cull. Instead, in the absence of guidelines to aid their culling decisions, producers have likely first decided on a culling rate. (High culling rates may reflect the producer's subconscious decision to calve all heifers or the producer's decision being made in the mistaken belief that the increased genetic progress and milk production leads to greater herd profit). Thus, faced with the desired culling rate, the producer knows how many cows need to be culled and then decides which cows to cull. Good managers likely have an intuitive ability to correctly rank the cows in terms of their profitability. Then starting with the least-profitable cows, they continue to cull cows until the number of culls dictated by the culling rate is reached. This suggests the decisions about which cows to cull are correct given the culling rate. In other words, prematurely stopping breeding and culling cows for reproductive reasons may be the result of an excessive culling rate, not problems with identifying which cows to cull. In order for the culling rate to be higher than optimum, some wrong culling decisions must have been made. This suggests that if an optimum culling rate were the target, the mistake of prematurely culling these animals may not be made.

The criteria dairy producers use to make decisions about culling cows are related to the farmers' motivations and goals and to their production system and social status (Beaudeau et al, 1996). Culling criteria differ between farmers, and they are sociologically structured. Culling practices are parts of farming styles. Culling decisions are completely embedded in the whole farming process. Different groups of

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farmers demonstrate different ways of thinking and deciding regarding culling. In comparing risk factors for culling in dairy herds, the risk of culling for clinically identifiable conditions such as reproductive failure and udder abnormalities can differ significantly between farms (Stevenson and Lean, 1998b).

Although significant advances in dairy herd management have been made in recent years through the development of computerized record systems for animal health and production, little progress has occurred at the farm level in making better culling decisions (Lehenbauer and Oltjen, 1998). Record systems have improved the quality and quantity of data that are available for review in making culling choices, but minimal change has occurred in the way these data are analyzed to determine which cows are to be culled from the herd. Many producers start with a list of cows producing less than some specified daily amount of milk based on the most recent test day information (Lehenbauer and Oltjen, 1998). This minimum level may or may not be related to a calculated minimum value for "break-even" daily milk production of the herd. Usually the stage of lactation, reproductive status, and age of the cow are examined next. Low-producing cows that are pregnant and approaching a stage of pregnancy that would provide a reasonably normal length of the dry period are often retained in the herd. Further consideration is typically given to some measure of genetic worth or contribution to herd value, such as pedigree information, percentage of herd mature equivalent production, or ranking of the particular cow in a listing of estimated relative producing ability. In addition, individual cow attributes are often considered, such as the chronic disease or conformational defects. Finally, the decision maker often gives careful thought to current dairy herd dynamics over both the short term and the long term. Consideration would typically include significant variations that would occur during the next several months in the number of dry cows and pregnant heifers expected to calve as well as any long-term goals for herd expansion or contraction. To some extent these herd-level factors often determine the actual number of cows to be culled at any given time. Most importantly, nearly all the analysis occurs by a rather ad hoc and informal process that usually incorporates heuristic methods (trial-and-error discovery) by the decision maker for reaching conclusions about which cows to cull. This process has also been described as nonprogrammed, depicting variable and unpredictable results being obtained at different times under similar conditions.

Factors Affecting Culling

Survival Analysis: The Effect of Diseases on the Risk of Culling

Most epidemiological studies of the relationship between diseases and culling have used standardized regression techniques such as logistic regression and discriminant analysis. These techniques provide a measure of culling risk. That is, they assess the degree to which various factors (e.g., disease) affect whether or not an animal was culled in a certain period. These studies tended to ignore when, in the lactation, disease and culling occurred (Beaudeau et al, 1995). Survival analysis is a more sophisticated statistical technique that assesses the effect of these risk factors on longevity. The *length of productive life,* defined as the number of days between the date of first calving and date of culling or death, is the commonly used measure of dairy cattle longevity. A common problem in analyzing longevity measures is the presence of incomplete (also known as censored) records because some cows have not been culled by the end of the study period. That is, a cow's longevity is not known until she has been culled from the herd. For those cows still in the herd at the end of the study, a censored measure of their longevity is the number of days between the date of first calving and the end of the study. This is termed *censored longevity data* because it only indicates the minimum true longevity. The cows with censored longevities could have been culled days, weeks, months, or years after the end of the study, but in any case their true longevities were greater than their censored longevities. To exclude these censored records from the analysis or to treat them as exact would bias the results. Survival analysis can correctly incorporate all the longevity data, including the censored data, into the analysis. The great advantage of survival analysis (with time-dependent covariates) in researching culling risks is its ability to incorporate the chronology of events into the analysis (Gröhn et al, 1998). For example, the stage of lactation when a disease occurs is included. Then the effect of the disease on the subsequent risk of being culled at various future stages of the lactation can be explored.

Using survival analysis with time-dependent covariates, researchers examined the effects of seven diseases on culling in 14 Holstein cow herds in New York state calving over a 1-year period and followed for an additional 9 months (Gröhn et al, 1998). The modifying influence of milk yield and conception status on the relationship between disease and culling was examined. The interactions between these factors and stage of lactation were taken into account. The seven diseases considered (and their incidence) were milk fever (0.9%), retained placenta (9.5%), displaced abomasum (5.3%), ketosis (5.0%), metritis (4.2%), ovarian cysts (10.6%), and mastitis (14.5%). Older cows were at a much higher risk of being culled. Calving season had no effect on culling. Higher milk yield was protective for culling. Once a cow had conceived again, her risk of culling dropped sharply. Cows that did not conceive had a significantly higher risk of culling than those that did. Mastitis was an important risk factor throughout lactation, but metritis was not. Milk fever, retained placenta, displaced abomasum, and ketosis raised the risk of culling at certain stages of lactation. Failure to consider the milk yield and conception status of the cows would have led to overestimation of the importance of these diseases on culling risk. The results indicate that dairy farmers consider many factors, including diseases, milk yield, conception status, parity, and stage of lactation, when deciding whether and when to cull a cow.

The total effect of 15 diseases on time of culling were studied in 39,727 Finnish Ayrshire cows that calved over a 1-year period and were followed until the next calving or culling (Rajala-Schultz and Gröhn, 1999a). The diseases studied were: dystocia, milk fever, retained placenta, displacement of the abomasum, metritis, nonparturient paresis, ketosis, rumen disorders, acute mastitis, hypomagnesemia, lameness, traumatic reticuloperitonitis, anestrus, ovarian cysts, and teat injuries. Parity had a significant effect on culling, the risk of culling being four times higher for a cow in her sixth or higher parity than for a first-parity cow. The effects of diseases varied according to when the diseases occurred and when culling occurred. Mastitis, teat injuries, and lameness had a significant effect on culling throughout the whole lactation. Anestrus and ovarian cysts had protective effects against culling at the time they were diagnosed. In general, diseases affected culling decisions mostly at the time of their occurrence. The exceptions were mastitis, teat injuries, and lameness, whose effects extended throughout the entire lactation, and milk fever, dystocia, and metritis, which also had an effect on culling decisions at the end of lactation. The results indicate that diseases have a significant influence in culling of dairy cows, and the effects of those diseases vary depending on both the time of

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disease occurrence and the stage of lactation when culling occurred.

The reproductive status of the cow was also important in the culling decisions of the Finnish cows. The knowledge about a cow's pregnancy status had a different effect on culling depending on the stage of lactation; the earlier the farmer knew that a cow was pregnant, the lower was the risk of culling (Rajala-Schultz and Gröhn, 1999b). When the number of inseminations was accounted for, the effect of pregnancy status decreased, distinguishing between cows that failed to conceive and cows that were never even inseminated. If a cow had been inseminated more than once, there was a protective effect against culling, which indicated that the farmer was willing to invest the time and effort to get certain cows pregnant in order to keep them. Pregnant cows are less likely to be culled, and high producers have a lower risk of being culled than low producers (Rajala-Schultz and Gröhn, 1999c).

A study on the effect of disease on length of productive life of Holstein cows in 47 herds in France assessed by survival analysis found the probability of a cow being culled increased in early and late lactation in older cows, in low-producing cows, and in cows with poor reproductive performance (Beaudeau et al, 1995). Udder disorders and reproductive disorders, mainly through poor reproductive performance, appeared to be the major health events influencing length of productive life. Mastitis before the peak of lactation or during the dry period increased the risk (relative culling rate in first lactation of 1.3 and 4.0, respectively). Teat injuries and nontraumatic udder diseases had a major influence on longevity. Cows with late metritis or early abortion had poor survival. Generally, the influence of health disorders was lower than the contribution of reproductive performances and score for milk production for changing the length of productive life of cows. Economic considerations are thus key criteria in culling decisions by the producer, whose objective is mainly to minimize losses from longer calving interval and lower milk production.

Age

Dairy cows have differing risks of being culled, depending on their age. Reports from Ontario (Dohoo and Martin, 1984b) and Ohio (Allaire et al, 1977) found the same age-related risks for culling, with some differences at earlier parities. In Ontario, cows were at highest risk of being culled between 3 and 4 years and after 7 years of age. A significant peak in the risk of culling occurred 300 to 400 days after first calving. In other words, the end of first lactation represented a significant culling decision point. In Australian dairy herds the risk of culling increased with increased parity (Stevenson and Lean, 1998a). This was accounted for specifically by increased risk of culling for calving disorders, reproductive tract lesions, and disorders of the udder. Risk of culling for failure to conceive remained constant throughout productive life. In Ohio the risk of a cow being culled increased more steadily with age than in Ontario. However, the risk in cows more than 7 years of age was equivalent in both regions. The annual culling rates according to age, for both studies, are shown in Table 8-7.

The reasons for culling change according to age. The most important reason for culling of first-calf heifers is reproductive failure. In a 5-year survey of culling in Holstein dairy herds in France, cows culled for infertility were younger and culled later in lactation (Seegers et al, 1998b). The relative importance of reproductive performance in culling decisions decreases as cows grow older. However, there is no absolute decrease in culling because of reproductive failure. The relative reduction in the importance of reproductive performance results from an increase of overall culling rate in older cows and an increase in the other reasons for culling (Allaire et al, 1977). The rate of culling for mastitis, other disease, and injury increases with age (Seegers et al, 1998b). Culling for low production is highest after the second lactation. This supports the observation that producers are reluctant to cull first-calf heifers for poor production, preferring instead to "give them a second chance" to produce better in second lactation.

Level of Production

Not surprisingly, low-producing cows are more likely than high-producing cows to be culled. Dairy cows have an additional 2.3 months of total herd life and 0.15 additional lactations in the herd for each 1000 lb (450 kg) of first-lactation milk production above the herd average (White and Nichols, 1965). The risk of culling increases significantly for

TABLE 8-7

*Influence of Age on Reasons for Culling in Dairy Cows**

	Age Range (Years)					
Reasons	**2-2.9**	**3-3.9**	**4-4.9**	**5-5.9**	**6-6.9**	**>7**
Low production (%)	15.3	26.3	24.4	21.8	19.6	12.6
Reproduction (%)	53.4	43.1	39.9	38.6	36.3	30.5
Mastitis and udder (%)	6.8	11.2	15.5	19.1	20.8	17.5
Disease and injury (%)	11.4	9.1	9.9	9.6	11.8	29.6
Miscellaneous (%)	13.1	10.3	10.2	10.9	11.5	9.8
TOTAL CULL RATE (% OF HERD)						
Ohio	15.3	17.9	21.5	23.1	24.7	30.2
Ontario	16	24	21	16	18	29

Adapted from Allaire FR, Sterwest HE, Ludwick TM : *J Dairy Sci* 60:254-267, 1977 (Ohio); and Dohoo IR, Martin SW: *Prev Vet Med* 2:771-784, 1984 (Ontario).

*Age in two different reference populations from Ohio and Ontario.

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cows with negative deviations from herd average fat-corrected milk production. For example, 29% of cows that achieve less than 90% of herd average production are removed from the herd, whereas only 17.4% of cows that produce in excess of 110% of herd average production are culled (White and Nichols, 1965). These data suggest that poor producers are almost twice as likely to be culled as good producers.

The reasons for culling and variation in culling rate for 4923 dairy herds served by the regional DHIA Center at Raleigh, North Carolina have been reported (Fetrow, 1988). The overall pattern of culling is similar, regardless of the average milk production level in the herd. However, some differences exist between high- and low-producing herds in the reported reasons for culling cows. High-producing herds sell a larger percentage of animals for dairy replacement purposes than low-producing herds, whereas low-producing herds report more cows culled for poor production. This difference likely reflects the high-producing herds' ability to sell their culls as replacements for lower-producing herds. High-producing herds report more cows culled for mastitis and low-producing herds have a higher death rate (Fetrow, 1988). As with any observational study, it must be emphasized that these observations are associations and do not imply a cause-effect relationship.

Disease

Disease as a risk factor for culling was considered in the survival analysis section earlier. Disease is commonly reported as a reason for the removal of a cow. However, reporting disease as a final cause for culling may be biased because often producers only consider the final disease event before culling. A disease may have a more fundamental role as a predisposing factor of the listed reason for culling. For example, chronic lameness may be the primary reason for a cow's poor reproductive performance, but the cow is likely to be reported as a reproductive cull. The literature on the associations between health disorders and culling of dairy cows has been reviewed. Certain diseases increase the risk of culling regardless of the production system being used (Beaudeau et al, 1993).

It is important to consider the effect of the presence or absence of a disease in the cow's lactational history as a risk of her being culled. A prospective epidemiological investigation in Canada evaluated the association of common disease events with culling and stage of lactation (Dohoo and Martin, 1984a). Several common diseases of dairy cows increase the likelihood of culling during the first 150 days of lactation. In this study the effects of age and farm of origin were controlled in the analysis. The relative risk of being culled was calculated for each disease condition.

The relative risk assigns a value to the increased likelihood that a cow that has experienced a particular disease is to be culled when compared with a cow that has had no disease. A more detailed explanation of relative risk and examples of this calculation are presented in Chapter 2. The relative risk for culling with some disease events is high (Table 8-8). Mastitis requiring systemic therapy increased the likelihood that a cow would be culled in the first 150 days of lactation by approximately ninetyfold. Cows that were recumbent with milk fever, even with successful response to therapy, had a twenty-nine-fold increased risk of being culled. Cows with teat injuries, foot or leg problems, and respiratory disease also had an increased risk of being culled. An elevated somatic cell count (SCC) was the only condition associated with an increased risk of culling after 150 days of lactation (Dohoo and Martin, 1984b). The association of a high SCC with late-

TABLE 8-8

Relative Risk of Being Culled After Common Predisposing Disease Factors

Disease Factors	Relative Risk*
Mastitis requiring systemic therapy	90
Mastitis requiring only local therapy	4
Milk fever with cow down	29
Disease of feet or legs	31
Teat injury	35
Respiratory disease	9

From Dohoo IR, Martin SW: *Prev Vet Med* 2:771-784, 1984.
*Relative risk is the increased odds that a cow with the disease condition will be culled in the first 150 days of lactation compared to a cow with no disease.

lactation culling was significant, even with the effects of age and level of milk production excluded. The culling of cows with mastitis is likely to reduce the risk of further infection in the herd. However, the costs of such action, in terms of reduced milk production and increased replacement costs, are generally thought to outweigh the benefits but not in all circumstances (Stott and Kennedy, 1993). Under conditions in the United Kingdom it is economically viable to cull certain cows because of mastitis for a variety of reasons. On the other hand, because milk yield does not decline with age in the later lactations, culling such cows may not be economical.

Examination of the relationship between diseases during two consecutive lactations and culling indicates the udder health and reproductive disease from both previous and current lactations can be primary health-related criterion involved in culling decisions (Beaudeau et al, 1994a). However, in general, culling appears to be related primarily to short-term effects than to consideration of the entire disease history of the cow.

The relationships between diseases of dairy cows and culling also depends on whether the cows were culled during early or late lactation has been investigated for Holstein cows in French herds (Beaudeau et al, 1994b). Nontraumatic udder disorders, teat injuries, milk fever, and the occurrence of both ketosis and assistance at calving were significantly associated with an increased risk of being culled early (odds ratio ranging from 1.6 to 10.3). Early and late abortion, late metritis, poor reproductive performance, retained placenta, nontraumatic udder disease within 45 days postpartum, and mastitis occurring in the first 3 months of the lactation were positively associated with a late culling (odds ratio ranging from 1.2 to 6.6). Cows with lower breeding value for milk and higher parities were high risk groups for culling. A lower level of milk production and occurrence of both reproductive disease and poor reproductive performance were risk factors for late culling.

The effects of parity, stage of lactation, and culling reason on the commercial carcass weight of French Holstein cows have been examined (Seegers et al, 1998a). In primiparous cows the effect of age at first calving led to differences for carcass weight. Locomotor disorders, accidents, and health disorders other than reproductive and udder disorders were associated with lower carcass weights. Infertility as a culling

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reason was associated with highest carcass weights, and large variations between farms were noted.

Body Conformation

No reported studies have prospectively evaluated the effect of body conformation or type classification scores on the risk of culling. Conformation is occasionally listed, though, as a reason for removal of cows from the herd (Westell et al, 1982). However, the appraisal of dairy type does not appear to be significantly associated with an increased risk of culling (Van Vleck and Norman, 1972). Conformation traits evaluated before 4 years of age were not effective in predicting the time or reason for a cow being culled.

Categories of Culling Reasons

Frequently the reasons for cow culling are assigned into categories. The apparent purpose of this categorization is to aid culling decision making and to target management interventions. The assignment of dairy cow culling into the categories of *voluntary* and *involuntary* is firmly entrenched in the literature. The appropriateness and usefulness of these categories have been questioned (Dohoo and Dijkhuizen, 1993; Radke and Lloyd, 2000). In contrast, there is strong support for emphasizing the economic nature of the culling decisions (Dijkhuizen et al, 1986; Marsh et al, 1987; Dijkhuizen and Stelwagen, 1988; Jones et al, 1995; Radke and Lloyd, 2000). An alternative system of categorizing culling reasons, *economic* and *biological* culls, are reviewed next, followed by a review of the traditional voluntary and involuntary system of categorization.

Economic and Biological Cull Categories

Essentially, all living animals culled from dairy herds are removed for economic reasons, but the disposal of diseased cows is typically considered to be forced replacement. However, in most of these cases the decision to remove an individual animal is based on economics (Dijkhuizen et al, 1986). The cow is not culled because she is no longer able to produce but because a replacement cow is expected to yield higher and more efficiently and therefore to be more profitable. Even though this culling decision involves an economic analysis that is performed subjectively, it is still an economically based decision.

Economic Culls. Many examples of economic culling can be described that would have previously been categorized as involuntary removals. A repeat breeder cow is culled as a reproductive failure on the assumption that continued attempts to achieve pregnancy will lead to an extended time in late lactation or in the dry period. Even though many of these cows may eventually conceive, the extended calving interval lowers their profitability sufficiently that a point is reached at which it is more profitable to replace them. A cow with a persistently high SCC because of subclinical mastitis can be a productive member of the herd and may even be successfully cured by dry cow therapy. However, this cow may be culled to avoid the direct cost from her mastitis and to remove her as a source of infection for the rest of the herd. Similarly, a thin cow with chronic lameness resulting from diseases of the feet may respond to repeated foot trimming and supplementary nutrition to improve body condition. However, this cow is judged to be an economic drain on the herd and is commonly culled. Even yearling or first-calf heifers sold as dairy replacements are usually sold with the expectation that their sale can net more profit than if they were retained as productive animals in the herd. Low producers are culled to make space for more profitable animals. Each of these examples represents an economic culling decision.

Biological Culls. These are defined as cows that are incapable of any reasonable level of production, so the producer has no sensible choice but to cull the animal. Examples of cows in this category include those with leg fractures or ruptured cruciate ligaments, lymphosarcoma, or a federally reportable disease such as brucellosis, as well as those that have died. In general these events are rare in dairy herds. This does not imply that none of these conditions can be treated medically or surgically. However, these are situations in which an individual animal is destined for removal from the herd unless there is major medical intervention. In these cases, decision analysis can be used to evaluate the economics of the therapy (Dohoo and Dijkhuizen, 1993). Since the decision to cull or treat the cow depends on economics, it is somewhat difficult to distinguish biological culls from economic culls.

Perhaps an appropriate category modification would be to change the biological category to a welfare category. An economic versus a welfare categorization in the dairy industry highlights society's concern over animal welfare. Such a categorization explicitly recognizes that an otherwise profitable cow is culled because it is in the best interest of the animal's welfare. However, it is difficult to think of a situation in which the animal would not have some underlying pathological condition (e.g., lameness) causing the decreased welfare. Thus, aside from increased awareness in the industry of welfare issues, it is unclear whether much would be gained over simply recognizing the culling as being due to the underlying condition (e.g., lameness).

Another situation that occasionally occurs in dairy herds is culling for emotional reasons. In such situations the producer may severely dislike the disposition of an individual cow or a recently-calved heifer may have an excitable temperament (Fetrow, 1988). However, these situations are rare and can be considered as biological reasons.

Voluntary and Involuntary Cull Categories

The voluntary and involuntary culling paradigm is a large source of confusion in the culling literature. It involves grouping commonly reported culling reasons into voluntary or involuntary categories. Table 8-6 presents some commonly cited reasons for culling according to voluntary or involuntary categories. The term "voluntary cull" has been used to define those animals that leave a dairy farm either because of low production in the absence of a known disease problem, or because the herd has an excess of animals and elects to sell individuals as replacements for other dairy herds. Involuntary culls have been loosely defined as those cows that leave the herd against the wishes of the producer. Within this definition, it is presumed that if the major problem, cause, or event had been avoided, then the cow would have had sufficient productive merit to have remained in the herd. Voluntary culling is generally regarded as desirable and involuntary as undesirable. The generally held perception is that voluntary culls are made for profitability reasons, whereas involuntary culls are financial detriments to the herd. There are a number of concerns with the voluntary versus involuntary categorization.

Miscategorization of Cows. The classification problems discussed previously in assessing the reasons cows are culled are compounded when those reasons are assigned to a voluntary or involuntary category. For example, as mentioned in the culling reasons section, cows with low production resulting from subclinical mastitis may be classified as low-production culls or mastitis culls. Cows classified as the former would be included in the voluntary culling category,

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whereas those assigned to the mastitis reason would be considered involuntary culls. Similarly, the other examples discussed in the culling reasons section (i.e., the low producer that has not conceived after one or two inseminations, and the significantly lame cow) could be included in the voluntary or involuntary category depending on which culling reason the cow was assigned.

Effect on Culling and Replacement Strategies. The categorization of animals as involuntary culls may hamper critical consideration of the culling and replacement strategies (Radke and Lloyd, 2000). Sometimes categorization as involuntary culls is incorrectly interpreted as the producer having no choice in the decision and therefore unable to change the decision (e.g., from Durr et al [1997b]), "Involuntary culling occurs when a cow has to be culled irrespective of her performance relative to that of her herdmates. . ."). Producers have a choice in all their culling decisions except for those animals that die or are strictly incapable of ever conceiving. For example, to prevent the culling of the cows whose breeding was prematurely ceased, a producer need only change his decision and not cull the cow. If producers and their advisors continue to believe they have no choice in many of their culling decisions, their opportunity to change these decisions and therefore their culling rates is severely limited.

Relationship with Profitability. The intent of the voluntary and involuntary categorization appears to be to increase profit. Unfortunately, this intent is somewhat misguided because it is not clear that the involuntary culls are necessarily detrimental to herd profit or that the voluntary culls increase herd profit. For example, the cows whose breeding was prematurely ceased and subsequently culled were still sufficiently profitable to have remained in the herd longer. These culled cows may have been included in the involuntary category of reproductive culls or in the voluntary category because of low production; in either case, these cows were profitable when culled, and changing the culling decision represents an opportunity to increase herd profit. Therefore, despite being classified as involuntary culls, these cows were still sufficiently profitable (relative to a replacement) such that they should have remained in the herd. Cows categorized as involuntary culls are not necessarily detrimental to herd profitability. If these cows were included as voluntary culls because of low production, then changing the decision on these cows represents a profit opportunity. Thus voluntary culls do not necessarily increase herd profit. Some simulation studies on the profitability of culling rates indicate that excessive voluntary culling can reduce producer profit (Allaire, 1981; Allaire and Cunningham, 1980). In addition, the poor milk production of the voluntary culls without clinical disease may also present a profit opportunity. For example, the poor production may have resulted from poor sire selection or inadequate heifer management. Simply put, the absence of clinical disease in a low-production cow does not preclude the possibility that the cow had the potential to be more profitable. In contrast, the economic perspective is to maximize the profit of all cows and to cull the least profitable. In economic terms, clinical disease is only a single, albeit important, management factor that can affect animals' profitability. In calling for improved herd husbandry to reduce culling rates because of involuntary reasons, the profitability of such interventions must be considered and not simply assumed.

Involuntary Culling and the Optimum Culling Literature. Ironically, much of the confusion over voluntary and involuntary culls appears to have originated from the culling rate simulation and optimization models. In the models a distinction was made between the culling for low production and failure to conceive and the culling for all other reasons. The culling decision based on low production and failure to conceive was typically made by the models based on comparing the profitability of the cow with that of her potential replacement. These were termed *voluntary culls*. The lost milk production and financial cost of cows culled for all other reasons were also included in the models. However, the model did not decide whether to cull these animals; the proportion of cows culled for all other reasons was assumed to be known and was an input to the model. These culling decisions not made by the model were termed *involuntary culls*. Involuntary culling included culling for mastitis, other health disorders, milking speed, temperament, pendulous udders, other husbandry related problems, and death. Involuntary culls included 2% infertile cows, which were cows that were inseminated but failed to conceive by the eighth month of lactation (Rogers et al, 1988a).

The percentage of involuntary culling was varied, and the level of involuntary culling was found to have a large impact on herd profit and on the optimum herd culling rate (Rogers et al, 1988b). (A decrease in the level of involuntary culling was somewhat compensated by an increase in the level of voluntary culling. For example, if 16.5% of the herd were involuntary culls, and the profit maximizing voluntary culling rate was 8.6%, then the total culling rate was 25.1%. However, if the involuntary rate was 13.6%, the most profitable voluntary rate was 9.8% for a total of 23.4%.) The focus on increased herd profit from reduced involuntary culls has been inaccurately extrapolated to the dairy industry on two accounts. First, the definitions of involuntary culls vary between the models and the industry. Failure to conceive—one of the most commonly considered reasons for involuntary culling in the dairy industry—is considered a voluntary cull in the optimization models. Second, the models' results have been misinterpreted. The models' focus on involuntary culling precludes considering improved reproductive performance as a method to improve profitability. This was undoubtfully the intent of the studies. More likely, the models were meant to highlight the large negative financial impact of the increased culling that is associated with decreased cow profitability, regardless of cause.

Retrospectively, the differing approaches toward reproductive culls also raise issues about the method of inclusion of involuntary culling in the models. The objective of the models was to determine the culling decisions that maximized producer profit. Presumably, the approach of not having the model decide whether to cull the involuntary culls, with their decreased profitability, resulted from the belief that these cows were so unprofitable relative to a heifer that the model would simply cull them all. Therefore, if the results of the decision were already known, there was little need to have the model reproduce this decision. However, it is noteworthy that conventional wisdom has included reproductive culls as involuntary culls (Table 8-6). This would imply that failure to conceive sufficiently impairs a cow's profitability to such a degree that there is little question about whether she should be culled. The culling models did not take this approach and, as described earlier in the culling guides, found that it is profitable to continue to breed cows longer than it commonly considered profitable. Thus it appears conventional wisdom on the unprofitability of involuntary reproductive culls is inaccurate. A natural extension of this is to wonder whether the assumptions about the relative unprofitability of other involuntary culling reasons are also misguided, and whether it would have been preferable for the culling models to have assessed the profitability of all culling decisions, especially those that are commonly considered involuntary. One of the optimization models was expanded to include the deci-

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sion of whether to cull cows with mastitis under Dutch conditions (Houben et al, 1994). Although the mastitis lowered the cows' profitability, in most cases the optimum decision was to treat rather than replace the cow. With a mastitis incidence of 9.7 clinical cases per 10,000 cow days, the model found 12.7% of the animals culled had mastitis. This is reasonably comparable with 8% of Dutch cows being culled for mastitis, given the inaccuracy of assigning culling reasons.

In summary, to increase herd profit, producers should concentrate on increasing the profitability of their cows. In terms of culling, the best culling decisions have been made if the least profitable cows are culled, regardless of the reasons. It is not clear how the classification of culls into a voluntary versus involuntary category aids the process of assessing their profitability. It is possible that, because of confusion and inconsistent definitions, the categorization has hindered the industry's efforts to make the best culling decisions.

Relationship with Genetic Progress. Involuntary culls are generally assumed to be detrimental to the herd's genetic progress. Simulation studies found that different cow culling systems have little effect on a herd's rate of genetic improvement, with sire selection playing a much more important role (Allaire, 1981; Pearson and Freeman, 1973; Korver and Renkema, 1979). This is consistent with the discussion in the genetics section of this chapter where it is reported that less than 10% of genetic improvement is due to cow culling and selection of herd replacements.

Reasons for Voluntary and Involuntary Culling. Even with the difficulties, it is useful to review the reported reasons for culling dairy cows. The results of several articles have been compiled in Table 8-6 (Fetrow, 1988). These results represent studies from several different regions in North America performed from 1962 to 1986. It is noteworthy that none of the reports used exactly the same culling reasons or categorized the reasons the same way. Construction of this table necessitated merging some of the categories into the "Disease" or "Miscellaneous" group. The results shown are proportions of culled animals attributed to each culling reason. They do not represent the percentage of the herd culled per year.

The average of the studies just mentioned suggests that approximately 40% of the animals culled from dairy herds leave for voluntary reasons and 60% are involuntarily removed. In other words, if 30% of a herd is culled during an average year, then approximately 12% is removed voluntarily and 18% involuntarily. However, there is considerable variation around these averages. Several studies of culling in dairy cattle have shown voluntary culling rates ranging from 49% (Westell et al, 1982) to 26.5% in a large Ohio study (Allaire et al, 1977). These differences may reflect large variations in the potential for export and local sales between these two geographic regions.

A survey of 340 dairy herds in England over a 1-year period found an average culling rate of 28.4%, with 7.2% resulting from infertility, 4.6% from mastitis, 2.2% from lameness, 2.6% from poor milk yield, 4.7% from age, and 7.1% from miscellaneous causes, including death (Whitaker et al, 2000). Infertility, mastitis, and lameness were responsible for half of the culling, with infertility being the most important factor. The average size of the herds was 133 cows, ranging from 33 to 432, with an average milk yield per cow per year of 6620 kg, ranging from 4000 to 9200 kg. The average annual rate of assisted calvings was 8.7%, injury 0.9%, digestive tract disease 1.3%, ketosis 0.4%, hypomagnesemia 0.7%, hypocalcemia 5.3%, mastitis 36.6%, and lameness 23.7%.

In a survey of 50 Holstein-Friesian dairy herds with an average of 178 cows over a 3-year period, the average total culling rate was 31.2%. Of the disposals, 54% were culled by the end of their fourth lactation. Infertility was the most common reason for culling (36.5%), followed by management policy (11.5%), mastitis (10.1%), BSE (7.4%), and lameness (5.6%). The most common causes of death were mastitis (8.9%) and BSE (11.5%), but 46% died for unknown reasons (Esslemont and Kossaibati, 1997). The culling rate ranged from 13.4% to 49.0%, which indicates a substantial difference between achieved and potential herd performance. Voluntary culling accounted for 11.3% of the disposals, and involuntary culling accounted for 88.7%.

Almost 60% of all cows in the average Quebec herd were either in first or second lactation, which means a very young population of cows. Over the period of time there was a decrease in culling for low production, from 16% in 1981 to 4.5% in 1994, and an increase in some of the major involuntary culling reasons, from 23% in 1981 to 32% in 1994, because of reproductive failure, mastitis, and lameness (Durr et al, 1997b). Another important result was that differences in overall culling between official and owner sampler herds were mostly due to sales and not due to voluntary and involuntary culling reasons. Dairy producers have been culling more intensively for low production in first (rather than later) parities, but a decrease in voluntary culling was observed in all parities. Culling rate increased with parity number for all major involuntary reasons, as opposed to sales, in which proportion of cows culled decreased with parity number.

The major reason for involuntary culling in dairy herds is reproductive failure. On average, 23% of all culls were removed for infertility (Table 8-6). Mastitis and udder health problems represent the next largest culling reason, resulting in 15% of all culls. Mastitis and reproduction accounted for more than half of all involuntary culling. Other categories with a significant percentage of the total culls are disease and injury (10.4%), death (3.3%), foot and leg problems (1.8%), and temperament (0.2%). A further 7.3% were attributed to miscellaneous reasons. Within each category, there is considerable variation among the studies reported. This variation is especially prominent for the reported death rates. Some reports do not include a death rate, and those that do vary from 0.6% to 11.8%. The more recent studies reported substantially higher rates of death as a cause of exit from the herd. For example, in a study of 32 commercial herds in Ontario, 7.9% of all culls were a result of death (Dohoo and Martin, 1984b). The 1986 DHIA records from the southeastern region of the United States reported an 11.8% death rate in cows removed from dairy herds. It is suspected that death rates in the earlier studies were underreported.

In a survey of why farmers cull dairy cows, reproductive failure was the primary reason, milk yield was second, and mastitis was third (Bascom and Young, 1998). Culling was lower for mastitis and milk yield, but higher for abortion and reproduction, in high-yielding Holstein herds than in low-yielding Holstein herds. Culling for mastitis and milk yield was lower in high-yielding Holstein herds than in non-Holstein herds. In a selection of Australian dairy herds, high milk yield in the first lactation was a risk factor for culling resulting from udder disorders. This suggests that managers of high-producing herds should pay particular attention to mastitis control and should select for sound udder conformation to reduce the effect of this type of involuntary loss (Stevenson and Lean, 1998b). Shorter calving intervals were also associated with an increased risk of culling for udder

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disorders and low milk production. This association may have been influenced by late abortions, creating a shortened calving interval and a greater tendency for farmers to cull these cows (Stevenson and Lean, 1998b).

In a historical cohort study on Dutch dairy farms, the risk of culling was higher for cows that had a caesarean section than for control cows (Barkema et al, 1992). Infection of cows with *Neospora caninum* is a significant cause of premature culling in dairy herds (Thurmond and Hietala, 1996).

METHODS OF REPLACEMENT HEIFER SELECTION

Following an insemination guide or targeting a given culling rate will determine the number of replacement heifers required. However, this determination may be somewhat difficult when the insemination guide is used, since it is not obvious exactly how many cows will be culled. Dairy herds with good reproductive performance and efficient heifer-raising programs can have enough young stock to replace over 40% of the cow herd annually. There is evidence that the majority of U.S. dairy producers raise and calve a large majority of their heifers (Heinrichs et al, 1994; Radke et al, 2000). This high replacement rate is consistent with the dairy industry's high culling rates previously noted and indicates the need for a method of heifer selection.

Surprisingly, there is little literature on methods of heifer selection. Lifetime profit corrected for the opportunity cost of postponed replacement is the correct method of ranking animals for profitability (Van Arendonk, 1991). This measure of an animal's lifetime profit explicitly recognizes that, in retaining the animal in the herd, the average potential replacement's profit is foregone. First-lactation milk production is moderately correlated with this measure of lifetime profit (Weigel et al, 1995) and therefore is a suitable objective for heifer selection. Surprisingly, there is little literature on methods of predicting heifers' subsequent first-lactation milk production. Genetic estimates of heifers' production abilities explain less than 7% of the within-herd variation in first lactation, mature equivalent milk production (Radke, 1998). On a small group of heifers, the heifers' genetic estimates for milk production explained only 3% of the variation in first-lactation milk production. The addition of the heifers' serum β-lactoglobulin levels explained 21% of the variation in first-lactation milk production (Mao and Bremel, 1995). However, analysis of this serum protein is not widely available, its production is limited to late gestation, and its biological relationship with milk production is unclear. Although genetics do not explain a lot of the within herd variation in first-lactation milk production, they are somewhat able to correctly rank animals, within herd, on subsequent production. Because the ability to rank animals on milk production is more important than the ability to predict actual milk production when selecting heifers to meet a target culling rate, genetics are useful in heifer selection. (Notice that comparing the profitability of all cows and heifers would require predicting the actual profit, and associated milk production, of each animal.)

Computer optimization and simulation programs have been used to generate heifer selection rules that maximize producer profit. Three scenarios were used that varied the percentage of heifers kept and looked at whether the raising of heifers resulted in a profit or loss (Radke et al, 1999; Radke, 1998). The study considered the period between the heifers' births and first calvings. Genetic estimates of the heifers' producing abilities were updated throughout this period. A complicated heifer selection rule that used each heifer's parents' predicted transmitting ability for milk, fat, and protein and their associated reliabilities was only slightly more profitable than heifer selection based on estimated breeding value of milk. However, use of the more complicated rule was not warranted, since the minimal increase in profit was not sufficient to compensate for the added complexity of gathering the necessary data and employing the more complicated rule.

With the information just described, heifer selection is a relatively simple matter. Based on the desired culling rate among the cows, the number of excess heifers is known. Heifers expected to calve within a given period should be separated into cohorts for selection purposes. An enterprise budget is used to determine the age at which it is most profitable, or least costly, to sell the excess heifers. Based on the genetic estimate of milk production ability for that period, the heifers that serve as cohorts for selection purposes are then ranked, with the lowest-ranking requisite number of heifers being sold.

The heifer enterprise budget should be divided preferably into periods that coincide with the release of new updated genetic estimates. Care must be taken in creation of the enterprise budget to only consider costs that would change in response to raising fewer heifers. For example, consider a farm that currently has heifer facilities. If, in response to raising fewer heifers, the profitability of the remaining heifers will not increase (because of less overcrowding, for instance), or if no other animals will take the place of the sold heifers, the facility cost cannot be assigned to any other animals and will be incurred regardless of whether the heifers are sold or not. As a result, in this case, the cost of the facilities should not be included in the cost to raise a heifer.

Basing heifer selection on genetics increased U.S. producer profit by over $20/heifer versus random heifer selection, which represents a 3% to 5% increase in farm profit. This $20 increase in profit accrues over the heifer's lifetime. The study also revealed that heifer selection based on genetic estimates captured only about 25% of the profit available if the animals could be ranked correctly on their subsequent milk production and profitability. This highlights the need for future research on methods of heifer selection. Evidence exists that U.S. producers are not using genetics in their heifer selection decisions (Radke et al, 2000).

RISK AND RETURN OF OPTIMUM CULLING AND REPLACEMENT STRATEGIES

Simulation models revealed that using an optimum culling rate increased herd profit from 2% to 40% (Radke and Lloyd, 2000). The large range in increased profit was due to an arbitrary culling method being compared with an optimum culling strategy for a given level of herd management. Thus the increase in profit is a function of how "good" the arbitrary method of culling was. Returns in the lower end of this range (e.g., 5%) seem quite plausible. In addition, heifer selection will increase profit another 3% to 5%. In summary, potentially, the strategy of an optimum culling rate and heifer selection strategy could be quite profitable to dairy producers.

Although calving fewer heifers and therefore having fewer animals available entails some risk in terms of the ability to respond to unforeseen circumstances (e.g., low production of the selected animals), heifer selection and lower culling rates also have favorable risk attributes. First, selection with sale of the excess heifers offers an immediate large source of cash flow from their sale revenue. Second, this management strategy is favorable in terms of its short- and long-term reversibility. In the short term, if a

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producer decides too many heifers have been sold and wants more heifers than are available, more can be bought or perhaps the sold heifers can be repurchased. However, purchase of animals may present a biosecurity risk to the herd. Longer term, if heifer selection is practiced and a producer is dissatisfied with the results, the former practice of calving all future heifers can be reintroduced. Health management, by providing a consistent environment that permits the expression of genetic potential, plays a critical role in minimizing the risk from heifer selection and lowered culling rates. Finally, modifying the culling and replacement strategy is favorable from a risk perspective because it does not involve large irreversible capital investments. Instead, a producer need only change his culling decision criteria and possibly modify other areas of herd management.

CUSTOMIZING OPTIMUM CULLING AND REPLACEMENT STRATEGIES

Herd Objectives

The objective of the simulation and optimization models is to maximize herd profit, but the models also provide information useful for herds with other objectives. For example, to maximize herd milk production the models suggest the herd culling rate should be approximately 35% (Allaire, 1981; Allaire and Cunningham, 1980) for North American herds. One study found that a 26% culling rate maximized milk revenue compared with the 23% rate that maximized the profit of Dutch herds (Van Arendonk, 1987). In addition, culling rates higher than the economically optimum range may slightly improve herd genetic progress. It is noteworthy that the range of culling rates common in North American herds is similar to the culling rates that maximize milk production. It is possible that the higher-than-economically-optimum culling rates in North American herds result from herd managers targeting maximum milk production as a proxy for maximum herd profit. The decision rule of comparing the cow and the replacement heifer can be modified to achieve any objective. If the objective is to maximize milk production rather than profit, the cow should be replaced if the average milk production of the heifer is greater than the cow's production in the next lactation. Similarly, if maximum genetic progress is the objective instead of maximum profit, the cow should be replaced if the heifer is genetically superior.

The results just mentioned indicate that decreasing the culling rate into the economically optimum 20% to 30% range slightly decreases herd milk production and genetic progress. The decrease in milk production is only a few percentage points because the drop in milk production resulting from selection from among fewer animals is partially compensated by having more cows in the later higher-producing lactations. At higher culling rates the cost of attaining higher milk production and genetic improvement is greater than their value, causing a decrease in profit. With all else being equal, higher-producing cows are generally more profitable. For a given culling rate, the highest-producing animals are desirable, but the strategy of higher milk production at any cost is not economically wise.

Customizing Individual Herd Culling Rates

As with any area of herd management, culling and replacement strategies need to be customized for each herd and adapted as circumstances change. An understanding of the principles of cow replacement decisions, and in particular the replacement decision rule, is powerful in customizing and adapting herd culling strategies. For example, the culling optimization and simulation models reveal that the optimum culling strategies are not sensitive to changes in the level of herd milk production, feed cost or milk price. Yet the optimum strategies do vary with reproductive performance of the herd and with changes in the price of a replacement animal relative to the price of a cull cow. These effects are all understandable, and in fact predictable, based on the principles and decision rules discussed earlier. The decision rule, which determines the optimum culling strategy, compares the profit of the potential replacement and the cow. Therefore any factors that affect the profitability of both the heifer and the cow have a minimum impact on the optimum culling strategy. Changing levels of herd milk production, feed costs, and milk price apply to both the cow and heifer and affect the profitability of each. Because these factors apply to each, however, the profitability of the cow relative to the heifer remains unchanged, and as a result the optimum culling strategy does not need to be customized or adapted as these factors change.

In customizing culling strategies for a given herd or adapting the strategy for a given herd over time, consideration is required of only those factors that affect the profitability of the cow or heifer, not both. There are three common factors that disparately affect the profitability of the cow relative to the replacement heifer: decreased cow milk production (extended calving intervals is a specific and important example), the price of a replacement heifer relative to the cull cow, and expansion of the herd.

Decreased Cow Milk Production

Profit from animal production is largely a function of continued high milk production. In addition to the animal's level of milk production, reproductive performance is also important to prevent the animal from spending an excessive amount of time in late lactation or the dry period. The profit-maximizing culling rate will be higher in herds with impaired levels of milk production or reproductive performance among the cows. For example, in the southern United States, a culling rate in the 40% range maximizes herd profit because of the deleterious effects of heat stress on the cows. The potential replacement's first-lactation milk production and profit are relatively unaffected by the heat stress. However, the deleterious effects of the heat stress on first-lactation reproductive performance and energy balance decrease milk production and profit in subsequent lactations. This factor is not limited only to herds that experience heat stress but is applicable to any herds in which the profit of the cows is decreased relative to the heifers, regardless of cause. If the cows have severely impaired milk production or reproduction because of health or management problems, a culling and replacement rate higher than the target range is preferable. Because of the decreased cow profitability, these herds will have decreased profit; freshening more heifers will help mitigate some of the loss. However, the underlying reasons for impaired cow performance should be investigated, since correcting these increases cow and herd profitability. As the cow profitability relative to the heifers returns to a more typical level, the profit-maximizing culling rate will decrease into the target range.

Extended Calving Intervals. One of the most common applications of the principle of maintaining cow production and profitability is management of cows with extended calving intervals (i.e., extended lactations or dry periods). Lowering the culling rate decreases reproductive culls, and as the culling guidelines clearly illustrate, breeding will continue for extended periods. This increased time

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to conception causes extended periods until the next lactation. Producers must be able to manage these cows so the production in the following lactation is not impaired. If the productive ability of these animals cannot be maintained, a higher culling rate is indicated. Alternatively, producers could consider the cost of altering their management practices (e.g., altering feeding management) to maintain the next lactation health and milk production of the animals with extended calving intervals.

Replacement Heifer Price Relative to Cull Cow

The second-common factor that requires adapting the culling and replacement rates is the price of a replacement heifer relative to the cull cow. Table 8-9, from one of the optimization models, provides an example of this factor's effect. As the price difference between a replacement and the cull cow increases from $450 to $650, the optimum culling rate decreased from 28% to 24%. Although the example is for the United States, the same principle is applicable even if a heifer is normally worth less than the cow. As the price of the replacement rises relative to the price of a cull cow, the optimum culling rate decreases, and vice versa. A pedagogical device useful for intuitively understanding the situation in which the heifer normally is priced higher than the cull cow is to consider the price difference as the cost of identifying poor-producing first-lactation animals. If a producer can calve a replacement, determine that she is a poor producer (and therefore of relatively low profitability), and then sell her for the same price as she would have sold for as a springing heifer, the producer has in essence paid nothing to identify this replacement as a low producer. In fact, the producer has a net profit from the animal's calf and milk production prior to her being sold. In this situation, it is most profitable to freshen all heifers (i.e., have the maximum biologically possible culling rate). This situation is potentially plausible for superior performing herds that are able to sell their culls for use as dairy animals in lesser herds. In contrast, most U.S. commercial herds will sell their culls for beef price and realize losses on the order of magnitude included in Table 8-9 for each first-lactation animal culled. In truth, the optimization models take the price difference (whether positive or negative) into account when developing the optimum culling rate. Therefore, regardless of whether the price difference between a replacement and cull is normally positive or negative, the optimum culling rate decreases if the price of a replacement rises relative to the cull's price.

TABLE 8-9

Effect of Cull Cow and Heifer Values on Optimum U.S. Culling Rates

Replacement heifer value minus cull cow value	Optimum culling rate
$450	28%
$550	25%
$650	24%

From Rogers GW, Van Arendonk JAM, McDaniel BT: *J Dairy Sci* 71:3453-3462, 1988.

This occurs because the price rise decreases the replacement's profit compared with that of the cow. Thus, even under Dutch conditions, for example, in which the price of a replacement is lower than a cull cow, the profit-maximizing culling rate will decrease as the relative price of the replacement rises (Van Arendonk, 1985; Van Arendonk and Dijkhuizen, 1985).

The culling literature indicates that the economic benefits of the increased rate of genetic improvement and increased milk production from higher selection pressure are simply not sufficient to compensate for the large losses described above. The target culling rate range is appropriate for a wide range of relative prices between replacement and culls, as illustrated by Table 8-9. Everything else being the same, the greater the price of the replacements relative to cull cows, the lower the profit-maximizing culling rate. This concept can also be used to adapt the culling rate to short-term price changes. For example, if the farmer were presented with the opportunity to sell replacements at an increased price, it would be economically rational to sell more of the heifers and thereby lower the culling rate.

Expansion of Herd

In herds undergoing expansion, the optimum culling rate is lower than the optimum rate if the herd maintained a constant herd size, because not all of the replacements are replacing or being compared with cows. By definition, the herd must have excess capacity to expand, permitting the replacements to enter the herd without necessitating the culling of a cow. In any herd with excess capacity the first priority should be to use the available capacity. As long as excess capacity exists, an animal should only be culled if it is not covering at least its variable costs and making some contribution to fixed costs. Depending on the degree of herd expansion and the number of available replacement heifers, the culling rate could be low. Only if the number of replacements is greater than that required to fill the herd to capacity and replace the animals that are not covering their variable costs should consideration be given to replacing cows (which are profitable) with heifers (which are expected to be more profitable). A method to assess the annual number of replacement heifers required to maximize herd profit during expansion is as follows:

1. The decision about how many cows to cull centers on comparing the profit of the potential replacement with that of the cow. This comparison is appropriate for the portion of the herd that currently exists.
2. Using the target culling rate for a herd of constant size and the number of animals currently in the herd, the number of heifers required to replace cows in the herd is known.
3. The desired level of herd expansion dictates the number of additional replacements required. If desired, allowances can also be made for the anticipated level of culling among these additional replacements during the year (i.e., the culling guides suggest 15% to 20% of first parity animals should be culled).

To permit herd expansion the number of replacement heifers entering the herd will be greater than the number of animals culled. When the culling rate is calculated for the expanding herd, it will be lower than the rate targeted for a herd of constant size.

Selecting and Implementing a Herd's Target Culling Rate

Assessment of the target culling rate for a herd should begin with determining the current culling and replacement strat-

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egy, including the culling rate, the rationale for the rate, and the method of selecting cows for culling and heifers for replacements. The information in this chapter can aid assessment of the current culling practices and replacement strategy and whether any modifications are required in any part of this strategy. In general, if possible, it is advisable to slowly implement any management change to give management sufficient time to respond to the changes and assess the results. This approach is applicable to altering the culling and replacement strategy of a herd. For example, if a herd with a 35% culling rate has target of 25%, in the next year it could aim for a rate of 32%. To achieve a rate of 32% would require the sale of approximately 10% of the heifers that would otherwise have calved and entered the herd.

In order to achieve a lower culling rate, the cow culling decisions must also be changed. For example, if the herd targeting a 32% culling rate next year averages 150 cows, it will need to cull only 48 cows instead of 53. Unless proactive steps are taken to alter the herd's cow culling decisions, it could easily end up culling roughly 53 cows again. A "monthly culling budget" will assist in effecting a lower culling rate and ensuring the target culling rate is achieved. For example, to achieve the 32% culling rate, on average the herd would designate four cows a month for culling. In terms of implementation of a target culling rate, when these cows actually leave the herd is not of particular interest; rather, the focus is on the decision of how many cows have been designated for culling. Obviously, the average number of cows designated for culling per month is just that—an average to which the farmer does not strictly adhere. The number in any month may be lesser or greater. The cumulative number of cows designated for culling in that year can also be tracked and compared with the target. The monthly culling budget, and the number of cows designated for culling year-to-date, integrate the herd's target culling rate into individual cow culling decisions. That is, the individual cow culling decisions are made with the goal of achieving the desired culling rate, rather than the culling rate merely being the end result of individual cow culling decisions.

HERD HEALTH IMPLICATIONS OF CULLING AND REPLACEMENT STRATEGIES

Modification of the culling and replacement strategy of a dairy herd has herd health implications. A reduction in the culling rate will allow problem cows that otherwise would have been culled to remain in the herd and require health care and management. One definition of herd health is the provision of an environment that permits the animals to express their genetic potential for production and profit. Such an environment is important for herd profitability.

Monitoring the reasons cows are culled helps to identify health management problems that may be impairing the profitability of the herd and the culling and replacement practices. If the least profitable cows have been culled, then the correct culling decisions have been made, regardless of the reason the cows were culled. Monitoring and evaluating the reasons the cows were culled can be useful in identifying management areas with the potential for biological improvement. The profitability of the potential interventions should then be assessed. The classification of culls as voluntary and involuntary is not helpful in identifying profitable interventions. At a minimum, the reasons each cow is culled should be recorded. These could include the reproductive status, production level, and any other germane information, such as disease status, at the time the animal was identified for culling.

CULLING COMPONENT OF THE COST OF DISEASE

Diseases often cause decreased productivity and profitability of an animal. If the decrease is sufficiently large, the animal is culled because a replacement heifer is expected to be more profitable. In assessing the cost effectiveness of preventing or decreasing the severity of the disease, the veterinarian must calculate the cost of the culling component of the disease. This cost has commonly been calculated as the price difference between the cost of a replacement heifer and the salvage value, if any, of the culled animal. This price difference method assumes that the animal, before the disease, was equally valuable as a replacement heifer, but it fails to recognize that the replacement may be superior or inferior. The cost of the culling component has been suggested as the difference in the value of the animal with and without the disease (Radke and Lloyd, 2000). To determine the value of the animal before the disease, her market value as represented by the price she would receive in a herd dispersal sale could be used.

In the absence of knowledge of the animal's market value, an alternative approach is to estimate both the number of lactations the animal would have remained in the herd if she had not been affected by disease and the profit associated with each lactation. If financial statements are available, the profit a cow will generate in a year can be estimated by dividing the total annual dairy enterprise profit by the average number of cows (Dohoo and Dijkhuizen, 1993). The profit of each lactation can also be gauged crudely by using the price of a replacement, which represents her expected future discounted cash flows from each lactation and her salvage value. If the average life of a replacement is three lactations, then she has a cash flow from each of three lactations and her salvage value. Ignoring the discounting of the cash flows to represent the time value of money, her price is the sum of the cash flows from three lactations and her salvage value. For example, if the average replacement price is $2000 and the average salvage value is $500, then the profit from her lactations is $1500 (i.e., $2000 − $500). If the average animal has three lactations, then on average there is $500 ($1500/3 lactations) profit per lactation. With this crude method, the cost of culling the cow in the current lactation due to the disease, whereas otherwise she would likely have been culled in the next lactation, is $500. In contrast, the price difference approach of subtracting the cost of the diseased cow's salvage value, if any, from the price of a replacement heifer would have resulted in an estimated cost of $1500 ($2000 – $500). It is difficult to understand how culling a cow one lactation earlier resulted in a loss of $1500. Notice also that if the analyst thought the animal would have remained in the herd for an additional two lactations, the profit-per-lactation method would suggest that the cost of prematurely culling her was $1000. In contrast, the price difference approach would have resulted in a cost of $1500. So although the cow's expected future number of lactations varied from one to two, by using the price difference method, the cost of her premature culling did not vary. The profit-per-lactation method is crude but can serve as a basis of initiating discussion with the producer on the culling component of the cost of disease.

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GENETIC IMPROVEMENT PROGRAMS FOR DAIRY HERDS

Genetic improvement is an area of herd management that traditionally has not been within the scope of veterinary practice. The consulting practitioner must first give attention to immediate problems in herd management and demonstrate to the client a quick improvement in herd performance; these are accomplished by changes in management and herd environment. This section shows that genetics contributes substantially to the long-term improvement of herd performance. Therefore the practitioner and client who envision a long-term consulting relationship must not overlook the long-term consequences of a herd's genetic improvement program. Certainly, a comprehensive assessment of a herd's current and future opportunities for improvement must include an assessment of genetic improvement policies and practices.

The second half of this chapter outlines the role of genetics in animal performance and herd improvement for production and health traits. A survey of the tools and methods for genetic improvement of dairy herds leads into approaches for assessing the herd's genetic status and planning the herd's genetic future. Attention is given to methods for improvement of yield traits that are well developed and for which many herd managers have some awareness. A special feature is the description of genetic improvement methods for health and reproductive traits. Although these systems are still undergoing development, producers have limited awareness of useful tools that currently exist for health and fertility traits. This material will enable the practitioner to become conversant in the language, concepts, and methods of genetic improvement.

TRENDS IN HERD IMPROVEMENT

Genetic improvement of milk production in dairy cattle is one of the great success stories in the history of agricultural science. Although the science of animal genetics began in the 1920s, successful practice of genetic improvement in dairy cattle began in the 1960s (Van Tassell and Van Vleck, 1991). During the 1960s, all of the modern tools needed for genetic improvement became available and were put into practice. These included AI, frozen semen, computer systems, centralized databases, and statistical techniques. These tools and methods have undergone continuous refinement. Today's systems for genetic improvement are well honed and highly sophisticated. These systems involve close cooperation among producers, production recording associations, AI organizations, breed associations, and government agencies.

Genetics has proved to be a powerful strategy for improving productive efficiency of dairy cattle. Fig. 8-1 shows the gains in U.S. Holstein breed average milk yield, breeding value, and environmental value by cows' year of birth; results are compared against a 1957 base (Animal Improvement Programs Laboratory, 2000b). From 1960 to 1995, 305-day milk yield per cow increased from 13,783 to 23,346 lb—a gain of more than 9500 lb in 35 years! The gains in breed average are due to gains in genetics, or breeding value, and gains in environmental value, i.e., feeding, management, and health care. The rate of improvement has accelerated: During the 1960s the breed average increased at a rate of about 140 lb per year; during the 1990s, annual gains increased to more than 500 lb per year. Genetic improvement before 1960 was slight by today's standards, but rapid improvements were being made in feeding and management at that time. By 1977 the total improvement after 1957 in breed average milk production was due equally to genetics and management. Since the late 1960s annual improvements

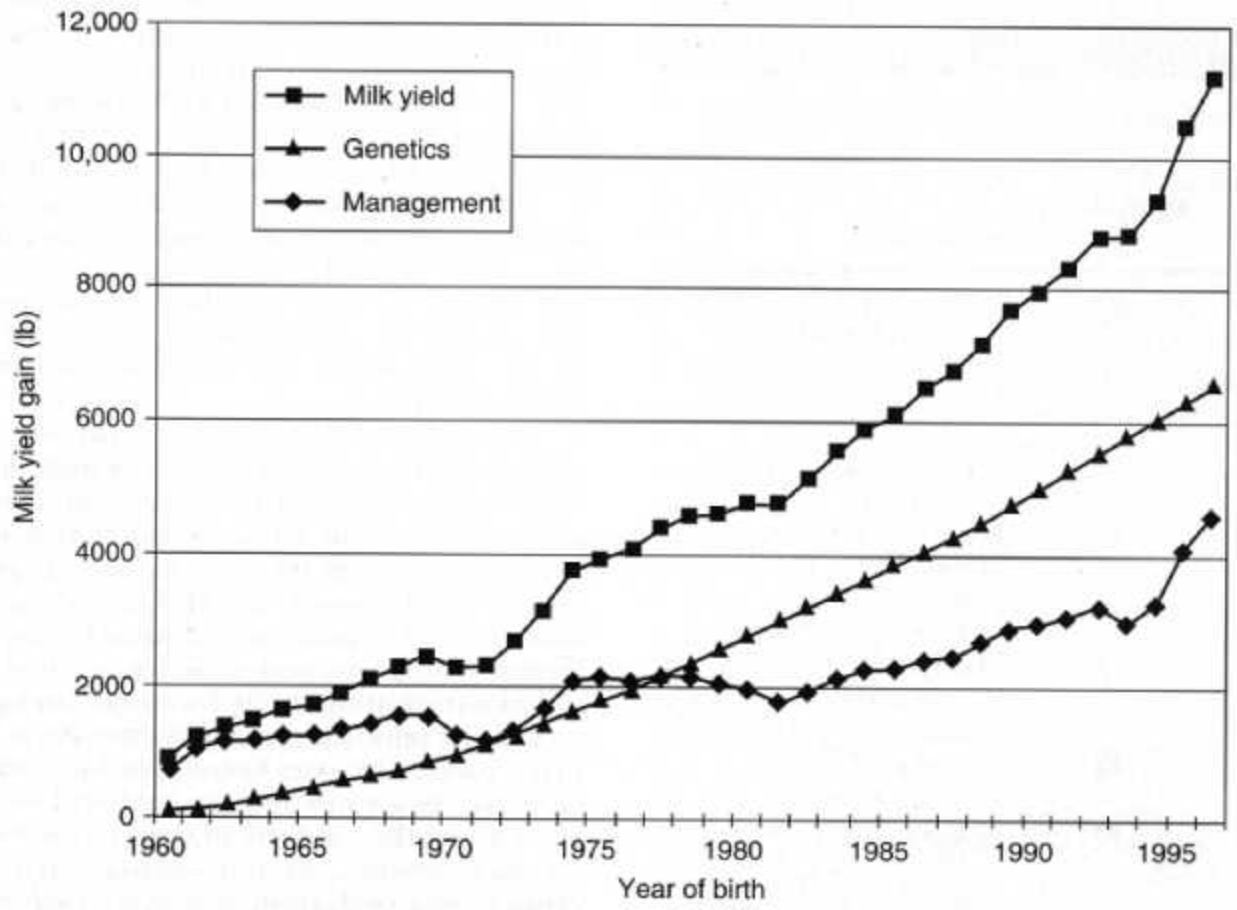

FIG. 8-1 Genetic, management, and phenotypic trends for milk yield in U.S. Holsteins. (Data from Animal Improvement Programs Laboratory, 2000. Available at http://aipl.arsusda.gov/main/data.html#gtrend [accessed March 5, 2001].)

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resulting from genetics have been greater than those from feeding and management. Throughout these years about 60% of the gain in breed average was due to genetics; the remaining 40% was due to management.

ROLE OF GENETICS IN INDIVIDUAL ANIMAL PERFORMANCE

Geneticists use *heritability* to express the degree of genetic influence on differences among cows in measures of performance. In statistical terms, heritability is the square of the correlation between breeding value and phenotypic value; also, heritability is the regression of breeding value on phenotypic value (i.e., the portion of difference between animals' phenotypic values that is due, on average, to the difference in their breeding values). Heritabilities for the yield traits are around 30%. This means that, on average, 30% of the difference in yield between any two cows taken at random is due to genetics. The rest of the difference is due to "environment," a category that includes feeding, management, health care, and many other known and unknown factors. Typical heritability estimates for several traits are listed in Table 8-10. Heritabilities are high for body size and the percentages of fat and protein. This implies that genetics has a relatively large influence and that environment has a small influence on these traits. Conversely, reproductive and health traits have low heritabilities, indicating that environmental factors contribute largely to the differences among animals and genetic differences are relatively small. For example, clean housing and sanitary milking practices are major environmental contributors to differences among cows for mastitis and somatic cell score (SCS), which are traits with low heritabilities.

TABLE 8-10

Heritability Estimates for Selected Traits in Dairy Cattle

Trait	Heritability (%)	Reference
Milk yield	30	Van Tassell et al, 1999
Fat yield	30	Van Tassell et al, 1999
Protein yield	30	Van Tassell et al, 1999
Fat percentage	61	DeJager and Kennedy, 1987
Protein percentage	59	DeJager and Kennedy, 1987
Somatic cell score	10	Schutz et al, 1994
Clinical mastitis	5	Emanuelson et al, 1988
Productive life	8	VanRaden and Klaaskate, 1993
Days open	4	Marti and Funk, 1994
Nonreturn rate	2	Weigel and Rekaya, 2000
Final type score	29	Weigel et al, 1998
Stature	42	Weigel et al, 1998
Calf mortality	4	Erf et al, 1990
Calfhood pneumonia	10	Muggli-Cockett et al, 1992
Paratuberculosis susceptibility	6	Koets et al, 2000

ROLE OF GENETICS IN HERD IMPROVEMENT

The large contribution of genetics to improvement of a population is shown in Fig. 8-1. Similar results can be expected in individual herds, although some will experience larger gains than others. Herds with a poor genetic background can obtain relatively rapid herd improvement through genetics. Herds with top genetics also will continue to improve by choosing bulls with high genetic merit, but their rate of improvement will be less dramatic.

Improvements in feeding, management, and health care can produce a desirable response in as little as a few days to as much as several months. Genetic gains are more gradual. Genetic decisions made today will not begin to impact the milking herd until 3 years from now, and the full impact will take 4 or 5 years. For this reason, it is important for herd consultants to focus first on problems that can produce a quick return. However, the long term must not be ignored, or else the client cannot remain economically competitive. Mistakes in feeding and management can be corrected in the short term; mistakes in genetics will exist for the lifetime of the animals. Therefore it is imperative to be consistent in implementing good genetic decisions.

The array of management remedies for solving dairy herd problems is extensive; the array of genetic tools is more limited. Genetic programs are well developed for improving milk yield, milk composition, and type characteristics. Genetic tools for improving reproduction and health traits are only beginning to emerge. Fortunately, a large amount of research is in progress toward the goal of developing genetic approaches to improving disease resistance and reproductive performance. These tools will continue to emerge and be enhanced over the next decade. This chapter focuses on currently available genetic technologies.

Differences among herds, like differences among cows, are due to both genetic and environmental factors. It has been estimated that 20% to 30% of the differences in milk yields among herds is due to genetics. Feeding, management, and health care should be seen as the major cause of differences in herd performance. Herds with the highest levels of performance are likely superior because of both high levels of genetics and high levels of management. Herds with low or moderate levels of performance may be limited in either genetics, management, or a combination of both. Evaluation of each herd's sire selection policies and management practices will reveal opportunities for improvement in both genetics and management. In spite of the fact that most of the difference among herd averages is due to feeding, management, and health care, more than 60% of herd improvement over the long term is due to genetics (Fig. 8-1).

Although 50% of the genes are derived from each the sires and dams of animals, over 90% of the genetic improvement in dairy herds is due to sire selection. Less than 10% of genetic improvement is due to cow culling and to selection of herd replacements from better cows (Van Tassell and Van Vleck, 1991; Dekkers, 1992). Genetic improvement on the dam side of the pedigree is limited by the fact that selection intensity and selection accuracy are low. Accuracy of predicted transmitting ability for cows is about 75% of the accuracy of sire selection. Selection intensity is limited by the fact that reproductive rates in cows are low—about one offspring per year. As a consequence, herd replacements must come from about the top 90% of cows in the herd. Sire selection, on the other hand, is more accurate than cow selection because genetic evaluation of sires is based on the performance of large numbers of their progeny. Furthermore, selection of AI sires is far more intense than cow selection because of the

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great reproductive capacity of bulls. In the first phase of selection, young sires are produced from the top 1% or 2% of cows in the breed mated to the top 2% to 4% of proven AI bulls. In the second phase, bulls are progeny tested with as few as 50 to 75 daughters in the United States to as many as 200 daughters in some European countries. Only the top 10% of these are put into active AI service after progeny testing. Because of the importance of sire selection to genetic improvement, this chapter will focus primarily on the many facets of sire selection for commercial herds.

TOOLS FOR GENETIC IMPROVEMENT

Information on which to base genetic selection decisions is well developed in many countries, including the developing countries. Although procedures and nomenclature are similar among the countries, many differences exist among countries in the data used for computing genetic evaluations, methods of data analysis, scale of measurement, and genetic base. The policies and practices of 31 countries that participate in Interbull were recently summarized (Interbull, 2000b). The procedures described here will be for those in North America.

Predicted Transmitting Ability

In the United States and some other countries, predicted transmitting ability (PTA) is the measure of an animal's genetic value. In its simplest form, PTA is a measure for ranking individual bulls and cows based on genetic merit. In general, PTAs are expressed in the same units of measure as the performance records from which the PTAs were derived, such as pounds or kilograms for the yield traits, percent for milk composition, and points for SCS or type traits. The practitioner needs only to list bulls in rank order of PTA to identify the best and worst for genetic improvement.

PTA, however, is much more than a number for ranking animals: It is a prediction of the differences in performance (e.g. milk yield) expected in future daughters of the bulls or cows. Most meaningful is the comparison between the PTAs of two animals. If PTA for one bull is 2000 lb milk and the PTA of a competing bull is 1200 lb, future daughters of the higher bull are expected to produce 800 lb more milk per lactation than daughters of the lower bull. This difference is expected to be the same in herds with low or high levels of performance. Comparing animals in this manner is a less abstract way to think about PTA.

Estimated Breeding Value

In Canada and many other countries, genetic evaluations are expressed as estimated breeding value (EBV) rather than predicted transmitting ability. The words "estimated" and "predicted" are synonymous, and no distinction should be inferred from those terms. Breeding value and transmitting ability are closely related concepts, but they are not synonymous. Breeding value expresses the effect of an animal's genes on the animal's own performance; transmitting ability expresses the effect of an animal's genes on the performance of its progeny. Genes and chromosomes in an individual occur in pairs: Breeding value measures the total effect of all pairs of genes and chromosomes on the animal's own performance. The sperm cells and egg cells that parents transmit to their progeny contain only one member of each gene or chromosome pair: Transmitting ability measures the average value of the genes in an average sperm cell or egg cell or the value of half of an individual's chromosomes. This equation can be expressed by the following:

$$\text{Breeding value} = \text{Transmitting ability} \times 2. \quad [1]$$

EBV and PTA are both measures of genetic merit and may be used in similar ways to select genetically improved sires and dams.

Comparing the EBVs of two animals measures the extent to which genetics causes a difference in performance of the two animals. Consider, for example, two cows with respective EBVs of 2600 lb and 1000 lb. Genes of the cow with the higher EBV are predicted to confer an advantage of 1600 lb to the performance of the higher cow compared with genes inherited by lower EBV cow. Because of environmental differences, the actual performance of the lower EBV cow may be higher than the performance of the higher EBV cow. Nevertheless, all the performance and pedigree information available provide a best estimate of the genetic differences between animals. With Equation 1, progeny of the cow with the higher EBV are expected to produce 800 lb (0.5×1600) more than the progeny of the lower EBV cow.

Genetic Base

Many definitions of genetic base are used; these differ from country to country and from trait to trait within a country. Users are cautioned to be especially aware of the frequency and timing of changes in genetic base in their country. A brief description of genetic bases in member countries is available (Interbull, 2000b).

The PTAs and EBVs are measured against a genetic base. Genetic base is an arbitrary reference point for comparison of genetic evaluations. EBVs and PTAs are relative measures, not absolute values. An analogy is the Celsius temperature scale for which the freezing point of water is a reference point. Whereas the freezing point of water is a constant reference point for temperature measures, genetic bases are defined in a variety of ways depending on the trait and country. In the United States, the genetic base is updated at 5-year intervals and remains fixed for each 5-year period. For example, from 1995 to 1999, the genetic base was the average PTA of cows born in 1990; this average for the yield traits is set to zero. From 2000 to 2004, the genetic base will be established as the average of cows born in 1995. Because bulls are more highly selected and fewer in number than cows, the PTAs of bulls are not used in setting the base. In Canada and many other countries, the genetic base is updated each year.

For many traits, the base population average for PTA or EBV is set to 0 (i.e., the average PTA or EBV of cows born in a certain year is set to 0 and evaluations for all animals are expressed as a difference from 0). As a result, genetic evaluations may have positive or negative values. If a cow's PTA for milk is 2000 lb, her daughters are expected to produce 2000 lb more milk than the daughters of an average cow born in the base year. In the United States, the genetic base for SCS is set to the breed average SCS for cows born in the base year; in this case, PTAs are always positive and resemble daughter averages.

It is important for users of PTA or EBV to be aware of the changes in genetic base and the consequence of those changes. Genetic improvement is quite rapid for some traits, like milk yield, and quite slow for other traits, like SCS. For traits undergoing rapid genetic improvement, updating the genetic base can cause a substantial reduction in the PTAs reported for individual animals. Updating the base does not change the ranking of animals, because all cows and bulls are measured against the same genetic base and the same amount of base change applies to all animals. In the Canadian scheme with annual updating of the base, a bull's EBV decreases a small amount each year. In the United States'

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system with 5-year updates, a bull's PTA is expected to be rather stable within each base period, but the PTA drops substantially when base changes do occur.

Reliability of Predicted Transmitting Ability or Estimated Breeding Value

Genetics and environment together cause differences in animal performance. The PTA measures the genetic merit; it is a prediction of average performance of future progeny. The PTA or EBV is calculated by sophisticated statistical techniques applied to the performance records of an animal (if any exist) and all known relatives; records of close relatives are weighted more heavily than records of distant relatives. Although performance records are used to predict genetic merit, environmental effects make performance records an imperfect predictor of genetic merit. Heritability measures how closely performance is related to genetic merit.

How closely does the *predicted* transmitting ability approximate an animal's *true* transmitting ability? True transmitting ability cannot be measured; PTA is inferred from the animal's own performance and the performance of all known relatives. New performance records are added to the data base and PTAs are updated at regular intervals two or four times per year in many countries. As new information is incorporated into the evaluation, PTA more closely approximates the true transmitting ability. How stable are these PTAs over time as new information is added? Measuring accuracy or stability over time of PTA is the role of *reliability*. When reliability is low, PTA may change dramatically as new records are included in the evaluation, because a prediction based on relatively few lactations is less accurate. As reliability approaches the upper limit of 99%, the PTA is based on such a large number of records that only small changes in PTA are likely to occur; the PTA is virtually equal to the animal's true genetic value. In statistical terms, reliability is the square of the correlation between PTA and true transmitting ability.

Reliability depends on heritability and on the number of records used in computing the PTA. Records on the animal itself and close relatives contribute more to reliability than records on distant relatives. As more lactations, daughters, and pedigree information are added to the data files, the reliability of an animal's PTA increases. Traits with low heritability require more performance records to reach a given level of reliability than traits with high heritability. Or for a given number of records, reliability will be lower for traits with low heritability, unless the number of records is extremely large; in this case reliability for all traits reaches 99%.

Reliabilities for cow PTAs are generally below 60% because living cows usually have few, if any, daughters. Reliabilities for bulls vary with the bull's stage of life. For young bulls with only pedigree information, reliability is typically 30% to 40%. Bulls with an initial AI proof involving 40 to 70 daughters have reliability of 75% to 85%. Reliabilities for older sires often reach the limit of 99% because they may have hundreds or thousands of daughters.

Reliability may be the most misunderstood and most widely misused quantity in genetic evaluation. Some have interpreted reliability as a measure of the fertility of a bull's semen. A common misuse of reliability is to select bulls on a combination of PTA and reliability (e.g., PTA times reliability). In effect, this process favors some bulls with high reliability and moderate genetic merit in preference to bulls with highest genetic merit and intermediate reliability. Daughters of bulls with higher PTA will perform better, on average, regardless of reliability. Whether reliability is high or low, the PTA is calculated so that a bull's future PTAs are equally likely to increase or decrease as new performance information becomes available. Some producers make decisions as though low-reliability bulls were more likely to decrease than to increase as new information becomes available. Rather, the increases or decreases in future PTAs will vary more widely for low-reliability than high-reliability bulls. For example, with reliability at 90%, chances are two out of three that a bull's PTA will stay within 240 lb milk above or below his current PTA. With reliability at 70% chances are two out of three that a bull's PTA will stay within 400 lb milk above or below his current PTA.

It is not widely known among producers and others that reliability is built into the calculation of PTA; this lack of information is one cause for the misuse of reliability. For bulls, PTA is essentially a weighted average of daughter deviation and parent average (PA). Consider the simplified case of two hypothetical bulls shown in Table 8-11. These bulls have equal amounts of pedigree data and the PA for both bulls is 0, equal to the genetic base. Also assume that the daughters of both bulls average 2500 lb of milk above their contemporaries (daughter deviation). The bulls differ only in the number of daughters. When the number of daughters is large, the daughter deviation is weighted heavily, PA has little weight, the PTA is only slightly less than daughter deviation, and reliability approaches 100%. Conversely for the bull with few daughters, daughter deviation receives less weight, PA is more heavily weighted, the PTA is substantially less than daughter deviation, and reliability is lower. In summary, the genetic evaluation procedures "discount" the daughter deviation for the number of daughters, so it is not necessary—indeed it is improper—to further discount the PTA for low reliability.

How to Use Reliability

How should reliability enter the sire selection process? First, it should be considered only in the final stages of sire selection. The initial screening of bulls should be based on PTA or EBV, the measure of genetic merit. For two bulls with similar PTAs, the practitioner might choose to use the bull with higher reliability. After the decision of which bulls to buy based on PTA, reliability is considered; the practitioner should purchase larger amounts of semen for bulls with high reliability and smaller amounts for low-reliability bulls. Since a bull's reliability increases over time, additional units of semen may be purchased if his PTA values remain competitive with other selected bulls.

Bulls with high reliability (e.g., above 80%) may be used extensively because their PTAs are not likely to change in future evaluations. Individual young, unproven bulls and proven bulls with low reliability should be used sparingly because their PTAs may change as new daughters are added to the evaluation. It may seem paradoxical, but several un-

TABLE 8-11

Effect of the Number of Daughters on Predicted Transmitting Ability (PTA) and Reliability When Daughter Deviation and Parent Average Are Equal for Two Bulls

	No. of Daughters	Daughter Deviation	PTA	Reliability of PTA (%)
Bull A	600	2500	2450	98
Bull B	30	2500	1600	75

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proven or low-reliability bulls with high average PTA may be used to breed a large portion of a herd. Although PTAs of individual bulls in the group may increase or decrease with new information, the average PTA of the group should change little. In effect, the average PTA of a group of bulls has a high reliability even though the reliabilities are low for individual bulls in the group. It is for this reason that a herd's participation in AI young sire sampling programs subjects the herd to very little risk for genetic merit.

TRAITS WITH GENETIC EVALUATIONS

Genetic evaluations are published for milk yield, yields and percentages of fat and protein, SCS, herd life, and some 15 conformation or type traits. Evaluations of bulls are commonly published for calving difficulty and sire nonreturn rate. In some countries, additional disease and functional traits such as milking speed and temperament are also published; these are described elsewhere (Banos, 1996; Ruane et al, 1997).

The percentile distributions for many of the traits just described are shown in Table 8-12. These distributions were based on 623 Holstein bulls actively marketed by the United States AI industry in August 1999. The genetic base for these PTAs was cows born in 1990; because of genetic gain, the PTA levels for the yield traits are high in relation to a contemporary cow population. A future change in genetic base will substantially reduce these levels for the yield traits. Rather, little change would be expected for the nonyield traits because genetic gain is limited. Distributions such as these can serve as benchmarks for measuring the quality of sire selection decisions on farms.

Variation among bulls shows the opportunity to create genetic improvement. Variability among bulls is indicated in Table 8-12 by the 90th percentile range, the difference between the 5th and 95th percentiles. The differences between percentile levels is stable over time and between genetic base changes. Variation within the top and bottom 5% of bulls is not reflected in the 90th percentile range; a large amount of variation does exist within these extremes. In fact, the difference between the best and worst individual bulls is more than twice the 90th percentile range for each trait.

Milk, Fat, and Protein Yield

Milk, fat, and protein yields are recorded through officially recognized production recording systems such as Dairy Herd Improvement (DHI). The basic record is test day yield recorded monthly or at less-frequent intervals; traditionally these test day yields are accumulated to a 305-day total that is analyzed by the genetic evaluation system. Some testing plans allow reduced frequency of fat and protein measurement. Many countries have implemented or are moving toward a "test day model" in which the individual test day yields are analyzed; this enables a more precise adjustment for environmental factors (Jamrozik et al, 1997; Wiggans and Goddard, 1997). Adjustments to the observed yields are applied to remove effects of age and season of calving, parity, days in milk, times milked per day, and days open. Typically records are standardized to mature age, twice daily milking, 305 days in milk, and 100 days open (Norman et al, 1995).

Large differences exist among bulls in genetic merit for the yield traits (Table 8-12). These traits are highly correlated; bulls high for one trait will often be high for the other two traits as well. Sire selection decisions should be based primarily on PTAs for these traits because they determine the revenue production of the dairy enterprise. In most countries an index is published that combines these three traits with weights that represent their local economic values.

Fat and Protein Percent

Genetic evaluations for the component percentages may be accomplished by direct analysis of the recorded percentages, or they may be obtained indirectly. In the United States these PTAs are computed indirectly from the PTAs for the yield traits. Equation 2 illustrates this calculation for protein percent:

$$\text{PTA P\%} = \frac{(\text{PTA P} + \text{BA P})}{(\text{PTA M} + \text{BA M})} - \frac{\text{BA P}}{\text{BA M}} \qquad [2]$$

where *BA* represents breed average, *P* represents protein yield, and *M* represents milk yield. In effect, the formula calculates a bull's daughter average for protein percent from the PTAs for milk and protein yield, then subtracts the breed average protein percent.

TABLE 8-12

Percentile Distributions for Predicted Transmitting Abilities (PTAs) for Selected Traits of Active Artificial Insemination Holstein Bulls in the United States

	Percentile*					
Trait	95	75	50	25	5	90th Percentile Range
Milk (lb)	2508	1965	1643	1319	559	1949
Fat (lb)	86	63	51	37	15	71
Protein (lb)	78	64	54	43	25	53
Fat (%)	0.14	0.02	−0.05	−0.1	−0.21	0.35
Protein (%)	0.08	0.04	0.01	−0.02	−0.07	0.15
Somatic cell score	3.44	3.30	3.20	3.11	2.98	0.46
Productive life	2.8	2.0	1.6	1.0	0.0	2.8
Type score	2.6	1.9	1.4	1.0	0.4	2.2

From National Association of Animal Breeders. Available at http://www.naab-css.org/db (accessed September 9, 1999).
*Percentage of bulls with PTAs below the values shown in the body of the table.

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A moderately negative correlation exists for the component percentages with milk yield; bulls with high PTAs for component percentages tend to be below average for PTA milk. Only a slight correlation exists between the PTAs for a component yield and percentage of that component.

An important question in sire selection is whether selection should be based on the component percentages or component yields. In most markets, higher revenues are generated by daughters of bulls selected for the component yields. The initial selection criteria should include the component yields. Component percentages may be considered as a secondary selection criterion among bulls that have high component yields. A common fault among producers is placing too much emphasis on the component percentages. The best decisions will be made by selecting bulls that rank high for an index of milk and component yields; especially an index that represents local milk prices.

Somatic Cell Score

Somatic cell count (SCC) is a commonly used indicator of mastitis. Results from many studies confirm that SCS is the most suitable single trait for the indirect reduction of the incidence of mastitis through selection (Mrode and Swanson, 1996). In many production recording programs, SCC is tested in bucket milk of individual cows each month. The SCCs are converted to scores, as illustrated in Table 8-13; each doubling of SCC is associated with a 1-point increase in SCS (Shook, 1993). The scores are averaged over a complete lactation. The lactation averages are adjusted for lactation length and age and season of calving (Schutz et al, 1995); the adjusted SCS values are used in genetic analysis (Shook and Schutz, 1994). Cows that are free of mammary gland infection maintain low SCS throughout lactation; cows with severe, chronic mammary infection have the highest lactation average SCS. Research has shown that mammary gland infection is the major cause of increased SCC; in the absence of infection, factors such as stage of lactation, age, and season have little effect on SCC (Harmon, 1994). A moderate elevation in SCC was once considered necessary to prevent infection; currently it is understood that moderate and high levels of SCC are due to subclinical infection and, therefore, are undesirable.

SCSs are preferred over SCCs for genetic evaluation because they have: (1) higher heritability (Ali and Shook, 1980; Monardes et al, 1983; Mrode and Swanson, 1996), (2) better discrimination between infected and noninfected cows (Berning and Shook, 1992), (3) linear relationship with milk yield loss (Raubertas and Shook, 1982), (4) normal frequency distribution, and (5) uniform standard deviations among animals within sire or herd (Ali and Shook, 1980). These findings are summarized in more detail elsewhere (Shook, 1982; Shook, 1993).

TABLE 8-13

Correspondence Between Somatic Cell Count (SCC) (cells/ml) and Somatic Cell Score (SCS) for Selected Values of SCS

SCC	50	71	100	141	200	283	400	566	800
SCS	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0

Shook GE: *Vet Clin North Am Food Anim Pract* 9:563-581, 1993.

Research has shown that sire evaluations computed only in herds with low average SCS are virtually identical to sire evaluations computed only in herds with high average SCS. Furthermore it was shown that heritability of SCS is similar in herds with low or high average SCS (Banos and Shook, 1990). Therefore SCS records from all herds are used in computing PTA SCS, and the recommendations for application of genetic evaluations for SCS are the same for herds at all levels of SCS.

Genetic correlation measures the tendency for PTAs or EBVs of two traits to vary together. Genetic correlation estimates between milk yield and clinical mastitis vary around 0.3, indicating a weak tendency for increased genetic susceptibility to mastitis as genetic improvement for yield takes place. Therefore it is important to include a measure of mastitis in sire selection programs. Estimates of the genetic correlation between SCS and clinical mastitis vary around 0.7; this implies that cows and bulls with high PTA SCS have greater genetic resistance to clinical mastitis (Mrode and Swanson, 1996; Shook, 1993). Because low SCS indicates the absence of mastitis, sire selection should favor bulls with low PTA SCS.

The frequency distribution of PTA SCS for U.S. Holstein bulls in active AI service is shown in Fig. 8-2 (Animal Improvement Programs Laboratory, 1999b); the bars show the percentage of bulls that fall into each category of PTA SCS. The PTA SCS of AI bulls ranges from 2.7 to 3.7, a difference of 1 point. In the same herd environment, daughters of the highest bulls will have geometric average cell counts that are double those of daughters of the lowest bulls. For example, in a herd in which geometric average of daughters of the lowest bulls is 150 cells/ml, daughters of the highest bulls are expected to average 300 cells/ml (150×2). In general, a difference of x units in PTA SCS for two bulls means that average SCC for daughters of the higher bull is expected to be 2 raised to the power x times the average SCC for daughters of the lower bull. For example, if the difference, x, between PTA SCS for two bulls is 0.8, the SCC for daughters of the higher bull is expected to be $2^{0.8} = 1.74$ times the SCC for daughters of the lower bull in the same herd environment. This relationship between SCC and PTA for SCS applies in herds at all levels of SCS (Banos and Shook, 1990). It should be noted that in the United States the genetic base for PTA SCS is set to breed average SCS rather than 0, as is done for other traits.

The 90th percentile range of PTA SCS is 0.46 points for active AI bulls (Table 8-12). This rather narrow range is due to the low heritability of 10% for SCS (Table 8-10) and, in

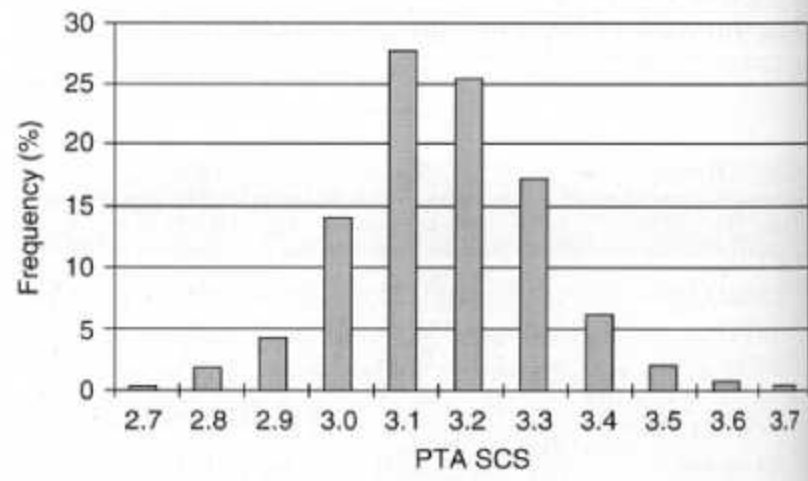

FIG. 8-2 Frequency distribution of predicted transmitting ability for somatic cell score *(PTA SCS)* for active artificial insemination Holstein bulls in the United States. (Data compiled from Animal Improvement Programs Laboratory: Genetic evaluation results, 1999. Available at http://aipl.arsusda.gov/main/data.html [accessed March 6, 2001].)

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some cases, limited numbers of daughters with SCS records. Also, this narrow range means there is limited opportunity for substantial genetic improvement of SCS. The great majority of bulls are within an acceptable range of PTA for SCS. The greatest concern is the 5% to 10 % of bulls with highest PTA SCS; these should be avoided unless they are truly outstanding for other more important traits.

Managers of herds with low average SCS may believe that sire differences in PTA SCS are of no concern in their situation. Research has shown that the genetic differences among bulls' daughters are similar in herds with both high and low average SCS (Banos and Shook, 1990). This means that herds with low average SCS will realize the same genetic improvement from selection against SCS as herds with high average SCS. Also, it means that sire selection recommendations should be the same for all herds regardless of herd average SCS. Sire selection against SCS should not be seen as a substitute for clean housing, good milking practices, and other methods of mastitis prevention. Daughters of bulls with low PTA SCS are as responsive to environmental conditions as daughters of bulls with high PTA SCS.

Herd Life

Herd life measures overall ability of the cow to stay in the herd. Long herd life is desirable because the cost of rearing a heifer to milking age is divided among more units of production, reducing the rearing cost per unit of production. Cows that are free of disease, with good reproductive performance and high milk production, have longer herd life. The phenotypic correlation of milk production with total herd life is 0.4; genetic correlation is 0.2 (Short and Lawlor, 1992). Studies have found herd life extended by 0.11 to 0.16 months per one percentile increase in cow's rank within the herd for milk yield (Boldman et al, 1992; Short and Lawlor, 1992); in other words, the difference in herd life between cows with the highest and lowest milk yields within a herd is 11 to 16 months. In some countries, total herd life is adjusted for yield, so it measures more directly the effects of health, reproduction, and other management factors on cow survival. Herd life adjusted for milk yield is often called functional herd life. It remains controversial whether genetic evaluations should be based on total or functional herd life.

Genetic evaluations in the United States are called PTA productive life (PL) and are based on total herd life, specifically the number of months in lactation from first calving until 7 years of age. A cow is credited with up to 10 months of herd life per lactation, and months are accumulated over all lactations. A cow's actual herd life is recorded when she is culled or reaches 84 months of age (VanRaden and Klaaskate, 1993). Average herd life for U.S. Holsteins is 25 months. Until actual herd life is known, it is predicted on the basis of age at first calving, total months in milk, and months in the current lactation. These predictions begin at 3 years of age. Early age at first calving and short calving intervals that result from good reproductive performance contribute to increased herd life. Daughters of sires with high PTA PL have these desirable characteristics.

For sire evaluation, PTA PL is based on pedigree data, actual and predicted PL of daughters, and the bull's PTAs for linear type traits. PTAs for udder conformation and foot and leg traits have been shown to improve the accuracy of PTA PL, especially when only predicted herd life is available for the majority of daughters or when daughter numbers are small. The frequency distribution for PTA PL for active AI Holstein sires in the United States is shown in Fig. 8-3. The 90th percentile range for PTA PL is 3 months (Table 8-12), whereas the full range is 6 months. This means that daughters of the highest bulls will have, on average, about 6 months more PL than daughters of the lowest bulls. As with PTA SCS, this narrow range of PTA PL is due to the low heritability of 8% (Table 8-10); this also indicates the somewhat limited opportunity for substantial genetic improvement of PL.

Calving Difficulty

Difficult calving, or dystocia, causes increased calf and cow mortality, higher veterinary costs, decreased milk production and a decline in reproductive performance (Dematawewa and Berger, 1997). Greater calving difficulty occurs with first parity parturitions, bull calves, and larger calf birth weights. Sire evaluations for calving difficulty are published

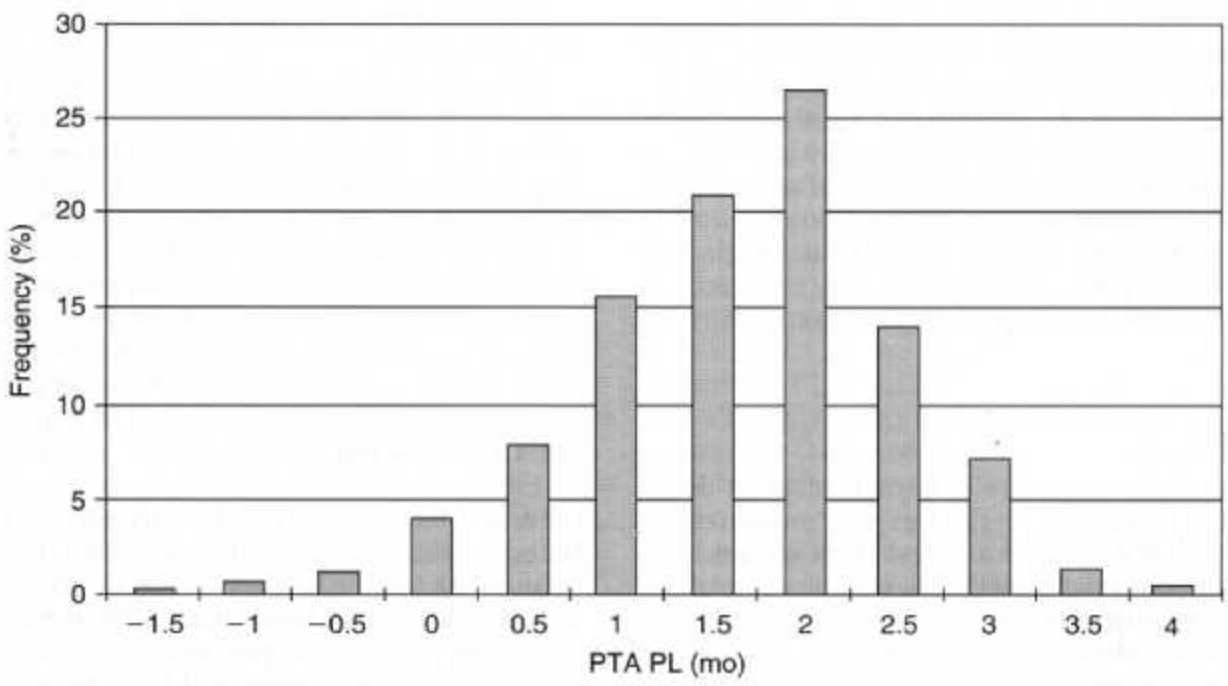

FIG. 8-3 Frequency distribution of predicted transmitting ability for productive life *(PTA PL)* for active artificial insemination Holstein bulls in the United States. (Data compiled from Animal Improvement Programs Laboratory: Genetic evaluation results, 1999. Available at http://aipl.arsusda.gov/main/data.html [accessed March 6, 2001].)

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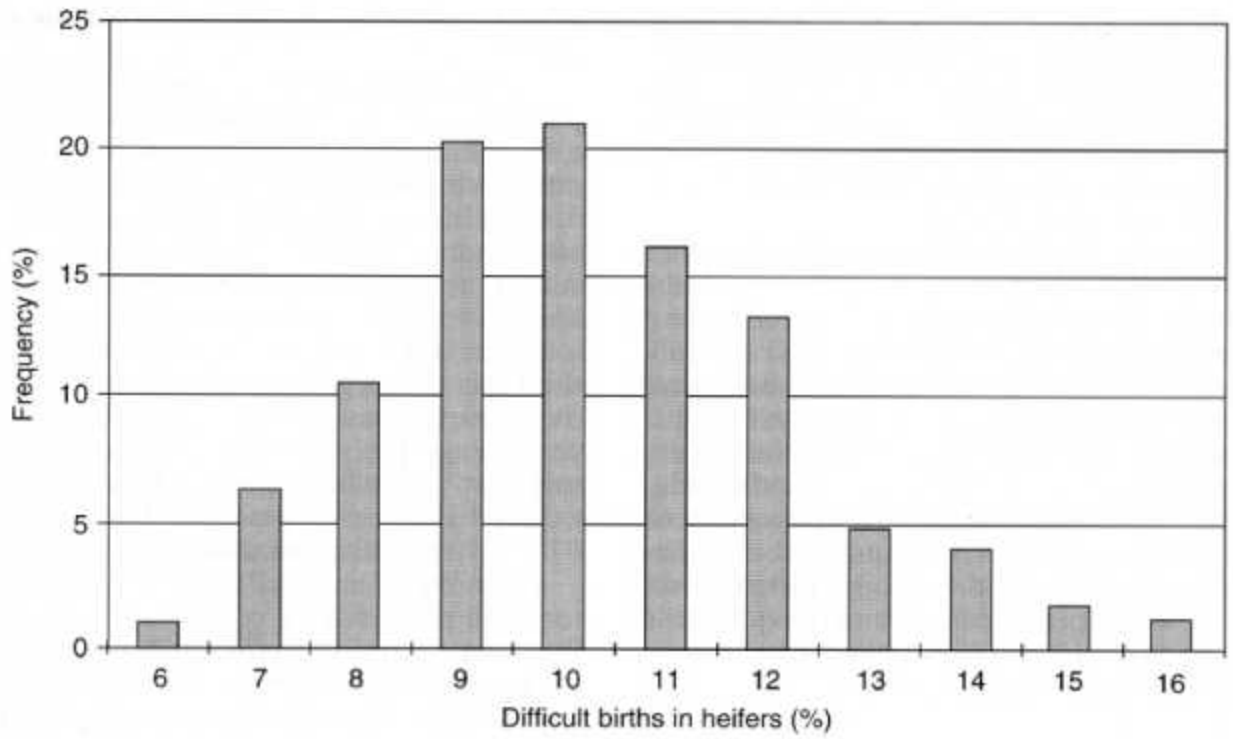

FIG. 8-4 Frequency distribution of calving difficulty evaluations for active artificial insemination Holstein bulls in the United States. (Data compiled from National Association of Animal Breeders: Active AI sire list, August 1999. Available at http://www.naab-css.org/db [accessed March 6, 2001].)

in many countries. Calving difficulty is influenced by the sire of the calf and by the sire of the cow. Some countries publish calving difficulty evaluations for both sire of calf and sire of cow.

Calving difficulty, as evaluated in the United States, is measured as the percentage of difficult births in heifers (Berger, 1994). Results are published only for sire of calf effects, although plans are in progress to develop sire of cow evaluations. Calving difficulty is scored on the farm and only for Holsteins. Fig. 8-4 shows the frequency distribution of calving difficulty evaluations of bulls; the bars show the percentage of bulls that fall into each category of calving difficulty. Sire summaries for calving difficulty range from a low of 6% to a high of 16% and average 10% (National Association of Animal Breeders, 1999). Evaluations are available for more than 80% of active AI Holstein bulls. Calving difficulty evaluations are not PTAs because they do not predict daughter performance. They measure the birth difficulty of calves sired by the bull rather than the genetic merit of the bull.

To reduce calving difficulty in the herd, yearling heifers should be mated to bulls with calving difficulty scores that are at or below the average of 10%. Up to 40% of semen purchased should be from bulls with low calving difficulty for use in this manner. Because calving difficulty is much less frequent in multiparous cows, calving difficulty evaluations may be disregarded when selecting bulls to mate with cows in milk.

Nonreturn Rate

Attainment of reproductive success is a major cost in dairy herd management. Heritability estimates for measures of reproductive performance are typically less than 4% and average around 2%. These low heritabilities indicate limited opportunity for genetic improvement; most efforts toward improving reproduction should focus on management. Nevertheless, geneticists are developing data systems and evaluation methods to take advantage of the genetic variation that does exist for this group of economically important traits. Genetic evaluations for measures of both male and female fertility will emerge as the research advances.

Currently, evaluations in the United States are available only for male fertility. These are not genetic evaluations in the sense that they do not predict the reproductive performance of a bull's sons or daughters. Rather they evaluate the fertility of the bull as a service sire. In the United States, estimated relative conception rate (ERCR) is computed for Jersey and Holstein sires. These evaluations are "relative" rather than absolute measures because they contrast the nonreturn rates among bulls within herds and aggregate these contrasts across herds. Data are from first services in commercial herds in the DHI system (Dairy Records Management Systems, 1999). The data are limited by the fact that many producers do not report service sires and breeding dates in their DHI records. Estimates are adjusted for the cows' early lactation energy-corrected-milk production, lactation number, stage of lactation, month of breeding, herd, and year. Only services reported in the most recent 3 years are included in the evaluation.

The frequency distribution for ERCR of active AI Holstein bulls is in Fig. 8-5 (Dairy Records Management Systems, 1999). The nonreturn rates for the best bulls are 11% higher than the worst bulls; 90 percent of bulls fall between −1 and +4. Reliability of ERCR and the number of first services on which the evaluation is based are published with ERCR. Results are published only for bulls with more than 300 first services. Reliabilities range from 48%, with 300 services, to 99% when more than 15,000 services are reported. Because of the limit of 300 services and the relatively rapid turnover of active AI bulls, ERCR results are available for only about one third of active bulls.

ERCR, when it is available, should be used as a secondary criterion for sire selection; primary selection should be based on the yield traits. Research has shown that each point of increase in ERCR has a value of about $2 in reduced reproductive costs in herds with 50% estrus detection rate and 50% conception rate per service (Pecsock et al, 1994). In other words, a producer could afford to pay up to $10 more per unit of semen for bulls with ERCR +3 compared with bulls with ERCR −2 (other factors being equal). Premiums of up to $5 per ERCR point per unit of semen are justified in herds with low (30%) estrus detection rate and low concep-

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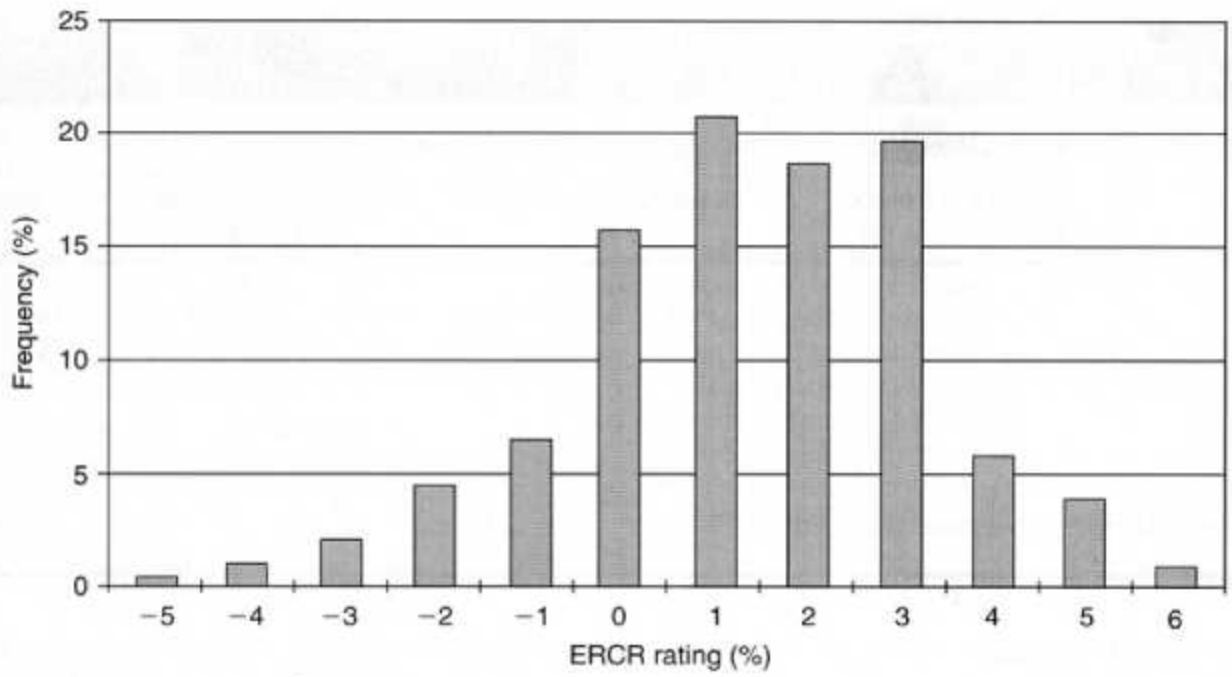

FIG. 8-5 Frequency distribution for estimated relative conception rate *(ERCR)* for active artificial insemination Holstein bulls in the United States. (Data compiled from Dairy Records Management Systems: AI sire fertility summary. Available at http://www.drms.org/sire.htm [accessed April 9, 2000].)

tion rate. The ERCR evaluations are more useful when choosing sires to breed milking cows because conception rates are higher in heifers. Also, bulls with the combination of high ERCR and low semen cost should be chosen to breed cows with poor reproductive performance.

MULTIPLE TRAIT SELECTION

With so many traits to consider when selecting sires, how can producers simplify the process and make profitable decisions? Two screening approaches are popular for reducing the long list of available bulls to a short list for more detailed consideration. These approaches are independent culling levels and selection indexes.

The culling level approach is perhaps the more intuitive one. It involves setting a lower limit for several traits; candidate sires are those that exceed the culling levels for all the traits. For traits such as SCS or calving difficulty for which lower values are more desirable, upper limits rather than lower limits are set. This approach is easily applied in spreadsheets and databases; also, it is used in many of the popular sire selection software applications.

Setting the culling levels is not easily optimized from an economic perspective. The principal disadvantage of the culling level approach is that some bulls outstanding for an economically important trait may be disregarded because they are below the culling limit for a trait of lesser importance. Several cautions should be observed when culling levels are established. These practices avoid some of the most serious problems in use of culling levels:

- Use culling limits for only a few, and only the most important, traits; avoid the temptation to set a culling level for every trait.
- Consider percentile ranges of PTAs, such as those in Table 8-12, as a guide in setting culling limits; without this guide the culling limits are highly arbitrary and may lead to overemphasis on unimportant traits and underemphasis on the most important traits.
- Set higher limits relative to the percentile ranges for the most important traits; use lower relative limits for less important traits.
- Update culling limits each year to stay current with genetic gain and genetic base changes.
- Try several sets of culling limits to find a desirable combination; look at the characteristics of bulls that are eliminated by the culling levels as well as the bulls that exceed the limits.

The selection index approach is preferred as a tool for screening sire lists. Research has shown that when economic values of traits are known, selection index will lead to selection of animals with a higher average economic merit than the culling level approach (Hazel et al, 1994; Hazel and Lush, 1942). Selection indexes combine the PTAs for several traits into a single number; each trait is weighted in proportion to its economic value. Sires are ranked on the index, and the highest ranking sires are chosen. In effect, a culling level can be set for the index alone. It is not necessary—in fact it would be redundant—to simultaneously set culling levels for an index and traits that are included in the index.

Specialists have developed a variety of selection indexes for different purposes. These are widely published for use by producers. Selection indexes are modified from time to time as new traits are introduced into the genetic evaluation system, as new understanding of the economic values of traits is gained, and as economic conditions change. Each country has developed its own selection indexes that correspond to local economic conditions and breed improvement philosophies.

Net merit index, developed and published by the USDA Animal Improvement Programs Laboratory, is widely used by commercial producers in the United States. This index combines PTAs for milk yield, fat yield, protein yield, SCS, and PL. This index is formulated in terms of net dollar income over feed cost per lactation. The formula for net merit (NM in the following equation) is as follows:

$$\begin{aligned} NM = {} & (\$0.022 \times \text{PTA milk}) + (\$0.56 \times \text{PTA fat}) \\ & + (\$1.40 \times \text{PTA protein}) + (\$11.30 \times \text{PTA PL}) \\ & - [\$28.22 \times (\text{PTA SCS} - \text{BA SCS})] \end{aligned} \quad [3]$$

where BA SCS represents breed average SCS, the genetic base for SCS; the genetic base for other traits is 0. The negative economic value for SCS reflects the fact that lower PTAs for SCS are desired. This index is currently undergoing review and revision (VanRaden, 2001).

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TABLE 8-14

Actual and Relative Economic Weights for Traits in Net Merit Index

Trait	Actual Economic Weight ($/unit)	Standard Deviation of PTA	Economic Value ($/SD)	Relative Economic Weight
Milk yield (lb)	.0217	800	17.36	3.1
Fat yield (lb)	0.56	30	16.80	3.0
Protein yield (lb)	1.40	25	35.00	6.2
Somatic cell score	−28.22	0.2	−5.64	−1.0
Productive life (mo)	11.30	0.9	10.17	1.8

PTA, Predicted transmitting abilities; *SD*, standard deviation.

The traits in net merit differ widely in the amount of genetic variation among animals (Table 8-12). Comparing economic weights in the formula for net merit makes it appear SCS is emphasized more heavily than production or PL; in fact, the opposite is true as illustrated in Table 8-14. Standard deviations for transmitting ability are shown in the third column of Table 8-14. Multiplying the actual economic weights in the index by the standard deviations gives the dollar value per standard deviation for each trait. Dividing the economic value per standard deviation for each trait by the economic value per standard deviation for SCS leads to the relative economic weights for the traits shown in the last column of Table 8-14. The economic weights for PL and SCS are based on limited research. The reader might speculate that these nonyield traits may have more economic importance than the index allows. However, one reason for the strong emphasis on the yield traits is their large standard deviation relative to the standard deviations for PL and SCS. Nature simply offers greater opportunity for improvement of the yield traits.

Another index widely used by registered Holstein breeders in the United States is the Type-Production Index (TPI), a name trademarked by Holstein Association USA. The TPI is formulated with relative rather than actual economic weights. The PTA for each trait is multiplied by a relative economic weight and divided by the standard deviation of PTA. The formula is:

$$\begin{aligned}\text{TPI} = \big(\{[(3 \times \text{PTA Protein}) / 19] + [(1 \times \text{PTA Fat}) / 22.5] \\ + [(1 \times \text{PTA Type}) / 0.7] + [(0.65 \times \text{UDC}) / 0.8] \\ + [(0.35 \times \text{FLC}) / 0.85]\} \times 50\big) + 576\end{aligned} \quad [4]$$

The udder composite (UDC) index combines the PTAs for six udder traits; the feet and legs composite (FLC) index is an index of four feet and leg traits. Both composite indexes weight the component traits in proportion to their correlation with herd life (Holstein Association USA, 1999). The coefficients 50 and 576 in the TPI formula only change the mean and range of index values; they have no influence on the relative weights of the traits. Each breed association publishes its own production and type index. Indexes similar to net merit and TPI are published in other countries.

Clearly, one index is not appropriate for all herds. For most commercial producers the index of choice would likely be net merit. Registered breeders will want to use their breed association's production and type index. A selection index should be chosen that is consistent with the producer's strategy for herd improvement. An appropriate selection index is an excellent tool for screening bull lists, (i.e., to quickly reduce the number of bulls for detailed consideration to a manageable number). Among bulls with high index values those with other desired characteristics such as low calving difficulty, low semen cost, low SCS, desirable type, high protein percent, and absence of genetic defects should be chosen. This approach ensures that the bulls ultimately selected are among the highest available for traits that are most important and places secondary consideration on the secondary traits.

BALANCING GENETIC MERIT AGAINST SEMEN COST

Balancing genetic merit against semen cost is an important economic consideration for herd managers. Investment analysis procedures have been developed and can be applied to this question (Everett, 1975; McGilliard, 1978). Herds with poor conception rate and high calf mortality expend more units of semen per heifer that enters the milking herd; herds in this category will realize a lower return on their semen expenditures, and these herds need to be sensitive to semen costs. Conversely, herds with high levels of reproductive performance that bring a high percentage of heifers born into the milking herd achieve a good return on semen investments; these herds can afford higher semen costs and should be more sensitive to the genetic differences among bulls. Financial health of the dairy enterprise is another important consideration. Herds with cash flow problems or high debt/equity ratios must focus on quick returns to the semen investment as in all other investments. Such herds must be more sensitive to semen costs and less sensitive to genetic values than herds with lower debt loads or cash flow concerns.

Not surprisingly, the decisions just detailed are complicated by the fact that bulls with better genetic merit come at a higher cost; they are in greater demand because of their higher genetic value, and high demand drives up semen prices. Semen prices are rather sensitive to the economic principles of supply and demand. Another complicating factor is that semen prices for the same bull can vary from day to day and area to area. A good buy on a particular bull on a given day may not be a good buy for another time or another herd.

Producers should avoid buying semen strictly on price. The lowest-cost semen from a genetically inferior bull indeed may be overpriced in comparison to somewhat higher-cost semen from a bull with substantially better genetic merit. "Overpriced" here means that the lower-cost bull may provide a lower rate of return on investment than the genetically better bull with higher cost. The converse can be true also; top genetic bulls can be overpriced in comparison with other bulls with substantially lower semen costs and only marginally lower genetic values.

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TABLE 8-15

Average Semen Price and Genetic Merit of Top 100 Holstein Bulls Selected on Expected Net Revenue for Three Levels of Herd Management

Management Level	Net Semen Price	PTA Merit Index	PTA Milk Yield	Protein Yield
High	19.96	213	2304	75
Average	19.25	210	2260	74
Low	17.50	201	2159	71

Compiled from Rogers GW: Expected net revenue, 1999. Available at http://www-das.cas.psu.edu/grogers/sire (accessed March 6, 2001).
PTA, Predicted transmitting abilities.

All herds have cows with reproductive problems; in general, these cows should be mated to bulls with lower-cost semen because as a group, these inseminations will produce a lower return per unit of semen. A portion of the semen purchase on any farm should include a certain percentage of low cost semen for use on cows with known reproductive problems.

Although much research has been performed on analysis of semen investment decisions (Blake, 1992; Everett, 1975; McGilliard, 1978; Rogers, 1990; Wilcox et al, 1984), rather limited software is available to support these decisions. Perhaps most prominent is the expected net revenue (ENR$) program, which is accessible through the Internet (Rogers, 1999). The program offers a choice of three selection indexes and two criteria by which to rank bulls; users may specify a culling limit for one trait from a choice of several traits.

The ENR$ computer program computes the expected net revenue from one unit of semen for a bull as a difference from the expected net revenue of a non-AI bull. The calculations consider the bull's semen cost, ERCR, and PTAs for the yield traits, PL, and SCS. The bull's genetic merit is expressed in the performance of his daughters and their descendants. Net revenues from the bull's descendants are projected for several future years and discounted to present value; the discounted net revenues are accumulated over time (Rogers, 1990). Discounting accounts for the fact that a future return on a current investment must be greater than the investment cost to produce a return on the investment. In other words the expectation of a future revenue has less current value than a current revenue of the same amount.

The ENR$ results can be computed for three levels of herd management. Herd management levels depend on the herd's conception rate and success of rearing herd replacements from birth to milking age. Although financial aspects of the enterprise are not factored into the calculations, herd management level can, to a limited extent, be a proxy for financial well-being. Herds with weak financial condition should choose the average or below-average level of herd management, even if reproductive and replacement management are excellent. The program is not designed to handle the combination of low herd management and weak financial condition.

Table 8-15 shows the average semen cost and genetic merit for the 100 highest bulls for ENR$ under three management levels. The higher management option places less emphasis on semen cost and more emphasis on genetic merit in comparison with the lower management levels; as a result the high management option tends to select sires with higher average semen cost and genetic merit. Users in fact may want to use the higher management option to choose bulls for the best cows, the low management level to choose bulls for cows with poor reproductive success, and average management level for the remainder of the herd. Because conception rate in heifers is substantially higher than in cows, a higher management level may be advantageous when selecting bulls to mate with heifers.

The ENR$ is another tool, like the selection indexes, for screening lists of bulls. It uses a selection index as the measure of overall genetic merit. The advantage of methods like ENR$ over a selection index is that they consider semen cost and rank bulls on basis of income over semen cost.

GENETIC DEFECTS

A veterinarian may encounter animals affected by genetic defects in routine practice and be called on to characterize a condition or diagnose a cause. Fortunately, such occurrences are rare; unfortunately, the rarity can leave the veterinarian unprepared for the task. A definitive diagnosis requires detailed analysis for which the cost often exceeds the willingness of a client to pursue a cause. As a result many defects remain undiagnosed or undiscovered. Nicholas et al (2000) have compiled a comprehensive database of references for genetic defects in livestock. Dennis (1993) provides an extensive presentation of genetic and other congenital defects in livestock.

Genetic defects are an important consideration in sire selection and mating. These cause various degrees of morbidity and mortality. Some are lethal in utero or soon after birth; others cause unthriftiness and make the animals useless in an economic enterprise. Most often, the inheritance pattern for genetic defects is autosomal recessive at a single locus. "Autosomal" means that the condition exists on one of the autosomal chromosomes instead of the X or Y chromosomes; as a consequence, inheritance is similar in males and females. "Recessive" means that the defective allele must be present in the homozygous state (i.e., it must exist on both chromosomes to cause the defective phenotype). The normal allele is "dominant" in this inheritance pattern because animals with one normal allele and one defective allele exhibit the normal phenotype; these animals are called "carriers" because they appear phenotypically normal but carry the defective allele. Although some genetic defects do exhibit more complicated inheritance patterns, the focus here is on those with the autosomal recessive pattern. In this section, a few of the defects that attained prominence in recent decades are reviewed.

Some Common Genetic Defects

Bovine leukocyte adhesion deficiency (BLAD) is due to a mutation in the gene that encodes the CD18 cell surface glycoprotein. The mutation causes reduced expression of adhesion molecules on leukocytes and multiple defects in leukocyte function. Neutrophils of affected animals are unable to migrate out of the bloodstream to enter infected tissues and destroy invading pathogens. Consequently, BLAD animals have frequent, recurrent bacterial infections, delayed wound healing, and persistent, extreme neutrophilia. Affected animals grow poorly, and the condition is essentially lethal by 6 months of age. A DNA test can identify carriers of the mutant allele. A survey in 1992 found a carrier frequency of 14% among U.S. Holstein bulls in AI and nearly 6% in Holstein cows. An active screening and culling program has nearly

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eliminated the defective allele from the AI sire population. The defective allele was traced to Osborndale Ivanhoe, a bull born in 1952 and used extensively in AI (Shuster et al, 1992).

Animals affected with citrullinemia appear normal at birth but become depressed within 24 hours. These animals are unable to eliminate ammonia, and they display neurological symptoms that become progressively worse leading to death within 1 week after birth. This condition is caused by a mutation in the gene that codes the urea cycle enzyme argininosuccinate synthetase. Citrullinemia became prominent in Holsteins in Australia where more than 10% of cattle were carriers. The mutation was traced to a bull, Gray View Criscross, bred in the United States. This bull was never widely used in his home country, and the condition never reached a serious prevalence outside of Australia. Carriers can be detected by a standard DNA procedure that identifies the specific mutation responsible for the condition (Robinson et al, 1993).

Syndactyly, or "mulefoot," is characterized by fusion of the claws on one or more legs. The condition is found in many breeds and cattle populations. This defect gained prominence in the United States in the 1960s by extensive use of a carrier Holstein AI bull. At that time, progeny testing was the only method for detecting carrier animals. Currently, the defective gene is known to exist on chromosome 15, but the specific locus has not been identified (Nicholas et al, 2000).

Deficiency of uridine monophosphate synthase (DUMPS) was traced in the United States to the AI bull Skokie Sensation Ned. The enzyme uridine monophosphate synthase catalyzes the conversion of orotic acid to uridine monophosphate, the precursor of all pyrimidine nucleotides, and is required for normal RNA and DNA metabolism. Embryos that are homozygous for this mutation die at about 40 days after conception. A consequence of mating a cow and bull that are both carriers of the defective allele is a subtle reduction in fertility resulting from early embryonic mortality. Lactating carrier animals exhibit half the normal enzyme activity and elevated orotic acid in both milk and urine. The latter two characteristics facilitate identification of animals with the carrier genotype. Carrier animals appear to have normal health and milk production characteristics. Carriers can be detected by DNA analysis or by orotic acid levels in milk or urine. A 1987 survey of active AI Holstein bulls in the United States found 1.4% were carriers (Shanks et al, 1987).

Progressive degenerative myeloencephalopathy, commonly known as "weaver," is a genetic defect in U.S. Brown Swiss cattle. This condition is particularly costly because symptoms only begin to appear at 5 to 8 months of age. Affected animals have difficulty controlling their rear legs, exhibit a staggering gait, and become progressively less able to walk or stand. The gene that causes the defect appears to be linked closely with a major gene for milk production. Results indicated that daughters of carrier bulls inheriting the defective allele from their sires produced 1500 lb more milk than their half-sibs inheriting the normal allele. This research found the weaver gene frequency in the cow population increased over time with frequency approaching 9% at the end of the study (Hoeschele and Meinert, 1990). Strong selection for milk yield, coupled with the apparent close linkage between the undesirable weaver allele and a major allele for high milk yield, likely propelled increased frequency of the weaver allele. The weaver allele occurred in many of the prominent Brown Swiss sires. Subsequent testing and culling of carrier bulls has reduced the occurrence of this defect.

Dynamics and Control of Genetic Defects

The prevalence of any one genetic defect follows a characteristic pattern over time. Such defects are numerous, but their allele frequencies and the frequency of affected animals are low and seldom observed (Dennis, 1993). Only when a carrier bull is widely used in AI does the frequency reach a noticeable level. In some cases the frequency may increase over two or three decades—four to six cattle generations—before it becomes apparent. Some level of inbreeding to the original carrier animal is often involved before the recessive allele appears in homozygous genotypes and the consequent defective phenotype. Studies of the pathology and inheritance of a defect may require another decade before control strategies can be developed.

Although AI is a powerful means of increasing the frequency of genetic defects, it is equally powerful for eliminating them. The AI industry and breed associations cooperate to test and identify carrier sires. In many cases the AI organization will immediately cull any known carrier bulls. Avoiding the use of carrier bulls (i.e., using only known homozygous normal bulls) leads to no further occurrences of defective genotypes. When carrier bulls are not used, the frequency of the defective allele in the cow population decreases by 50% of the population frequency of each cow generation. Although the defective allele is never completely removed from the population by this process, its frequency is reduced to low levels. When carrier bulls are continued in AI service, their carrier status is widely published. In this scenario the defective allele frequency may continue to increase or it may decrease at a slow rate depending on the number of progeny produced by carrier bulls.

In the United States, breed associations code animals with genetic defects (Table 8-16). These codes are published as an integral part of the animal's registered name. One set of codes indicates animals that are carriers of the defect. Another set of codes identifies animals that have been tested for the defective allele and found to be homozygous for the normal allele. Virtually all AI sires are tested for any defects they may have inherited from carrier ancestors. Few cows are tested. The absence of a code means the animal is not known to be a carrier, has not been tested for carrier status or is not likely to be a carrier based on pedigree data.

There are two strategies producers can use to control the frequency of genetic defects. The most effective strategy is to use only bulls known to be homozygous for the normal allele; this completely avoids the possibility of producing defective offspring and reduces the frequency of the defective allele in the herd. The second strategy, which allows the use

TABLE 8-16

Codes to Identify Animals Known to Be Carriers of Genetic Defects or Tested and Found to Be Homozygous for the Normal Allele

		Status Code for Genetic Defect	
Genetic Defect	**Breed**	**Carrier**	**Tested Normal**
BLAD	Holstein	BL	TL
DUMPS	Holstein	DP	TD
Mule foot	Holstein	MF	TM
SMA	Brown Swiss	M	TM
Weaver	Brown Swiss	W	TW

BLAD, Bovine leukocyte adhesion deficiency; *DUMPS*, deficiency of uridine monophosphate synthase, *SMA*, spinal muscular atrophy.

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of heterozygous, carrier bulls, is to avoid mating carrier bulls to daughters or granddaughters of known carrier bulls. Although the second strategy tends to increase frequency of the defective allele in the herd, it is not likely to produce affected animals. Affected animals result when both parents are carriers; if either parent is homozygous for the normal allele, no affected progeny can result.

EVALUATING A HERD'S GENETIC STATUS

Identifying problems in herd management and opportunities for improving herd profitability requires assessing the current situation and comparing these findings against industry benchmarks. Two approaches to evaluating a herd's genetic status are presented. One approach is based on herd average PTA of cows' sires; the other is based on cows' own PTAs. Each method requires its own benchmark for comparison. A crucial requirement for both methods is the availability of records. For some herds sufficient records may not exist for either method. Because the national genetic evaluation program is based on data from DHI herds, these herds have the best opportunity for evaluation of genetic status.

Average Sire Predicted Transmitting Ability

Average PTAs of sires and service sires directly measure genetic inputs. Although the sires represent only half of the genes that form a new generation of animals, they account for most of the genetic improvement. In an AI-sired population, more than 90% of genetic improvement is attributable to sire selection. Sires are proven to a higher level of reliability than cows, and only the most elite sires and dams are needed to produce a new generation of young bulls. While the average PTA of sires of milking cows represents decisions made years ago, the average PTA for service sires represents recent decisions. To identify and correct genetic problems in a herd, it is essential to understand and, if warranted, change the manager's sire selection policies.

Many DHI processing centers provide a summary of average sire PTAs similar to that in Table 8-17. Typically these reports show average PTAs for service sires (i.e., sires of calves in utero and other recent inseminations) and several age categories for heifers and milking cows. The producer must report sire identification for individual animals to enable the DHI processing center to compile this report. To assess the quality of this report for a particular herd, it is important to determine what percentage of animals are included in these averages. A low percentage of reported sire identifications in any age category limits the usefulness of the report. Because of the constant increase in average PTA of bulls available through AI, a trend of increasing average PTA with younger age groups, as in Table 8-17, will be seen in herds that are making good genetic progress.

For herds not on the DHI program, evaluation of a herd's genetic status requires additional work. If AI sires are used and if service sires and sires of animals in the herd have been recorded, the task is not difficult. Tables such as Table 8-17 can be constructed by hand. PTAs of AI bulls can be obtained from the bull stud or from one of the web resources (e.g., http://aipl.arsusda.gov/main/queries.html). For traits and years of interest, calculate average PTA of sires in categories of animals' years of birth; the average should be weighted by the number of animals or services by each bull. Most important is the average PTA of recently used service sires because this documents recent decisions. Without sire identification, no assessment is possible.

If the herd uses non-AI bulls, it may still be possible to obtain a genetic measure of the genetic merit of the herd; whether this can be done depends on the source of the bulls. If the bulls are from a purebred herd that participates in the DHI program, it will often be possible to identify the sire and dam of the non-AI bull, and the PTAs of the sire and dam can be obtained from http://aipl.arsusda.gov/main/queries.html. A PTA for the non-AI bull is not likely to be available, but analysts can calculate a PA for the bull as follows:

$$PA = [PTA\ (sire) + PTA\ (dam)] / 2 \quad [5]$$

Reliability of the PA is as follows:

$$Reliability\ (PA) = [Reliability\ (sire\ PTA) + Reliability\ (dam\ PTA)] / 4 \quad [6]$$

A table such as Table 8-17 can be compiled using PAs of sires and service sires. For herds that use both AI and non-AI bulls, PAs and PTAs can be co-mingled in the same herd average because the genetic base is the same in all cases.

Herd Average Cow Predicted Transmitting Ability

Herd average cow PTAs for the yield traits provide an easy opportunity to evaluate a herd's genetic status. Some DHI processing centers provide a summary similar to Table 8-17 for average PTA of cows. Only cows with reported sire identification can be included in a summary of this kind. Cows without reported sire identification cannot contribute to the genetic evaluation system; nor can such cows have their own PTA. Average PTA can be calculated for all cows in production, or a separate average could be computed for each year

TABLE 8-17

Typical Dairy Herd Improvement Summary of Herd Average Sire Predicted Transmitting Abilities.

Genetic Group	Total Number	Milk (lb)	Fat		Protein		Net Merit ($)
			%	lb	%	lb	
Service sires	142	+2049	−0.06	+62	+0.02	+69	+250
Heifers	221	+1479	−0.01	+51	+0.03	+52	+190
First lactation	98	+1414	+0.00	+51	+0.01	+46	+177
Later lactation	171	+ 841	−0.04	+40	+0.03	+32	+123
All cows	269	+1049	−0.03	+44	+0.02	+37	+142
State average	—	+ 715	+0.00	+26	+0.02	+25	+ 88

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by cows' year of birth. Because of rapid genetic advance through AI, cows born recently should have higher average PTA than cows born longer ago. A listing of PTAs for each cow in the herd is available from DHI processing centers. To evaluate the quality of this measure, observe the percentage of cows for which PTAs are available. If this percentage is low, other means of herd evaluation will be necessary. Nevertheless, the herd average is a good measure of the genetic merit for that portion of the herd that does have PTAs. A report of this kind is not possible for non-DHI herds.

This approach to genetic evaluation of a herd is appealing because animals that contribute to herd average production can be included in the genetic measure of the herd. A disadvantage of this method is that the breeding decisions reflected in this measure were made from 4 years to as many as 10 years ago, depending on the ages of the cows. Whereas average sire PTA measures genetic inputs, herd average cow PTA measures the outcomes of the herd manager's breeding decisions. A year-by-year summary of the herd lactation average and average PTA demonstrates progress in both genetics and management. This can be a great source of satisfaction for a producer to trace the herd's genetic progress over time.

Benchmarks

Assessing a herd's genetic status involves comparing the herd average PTA with an appropriate benchmark. Because genetic improvement for the yield traits is so rapid, it is important to use benchmarks that correspond to the animals' years of birth. In addition, it is crucial that herd average PTAs and benchmarks are from the same genetic base.

The average PTA of currently active AI bulls is an appropriate benchmark for herd average PTA of service sires; recent service sires are drawn from this population of active AI bulls. Among several other sources, this benchmark can be found for all breeds in the United States at the USDA website (ftp://aipl.arsusda.gov/pub/bulls/evalrpt.txt). Because of the large number of AI bulls marketed in the industry, it should seldom be necessary to use an individual bull that is below average for the yield traits. Also, because better bulls are used more heavily in the industry than poorer bulls, the simple average of bulls' PTAs that is calculated by USDA is below the average PTA weighted by units of semen sold. For these reasons, the herd average PTA of service sires should be above the national average PTA of active AI bulls.

Benchmarks for PTAs of sires of milking cows can be found at the website http://aipl.arsusda.gov/main/data.html#gtrend. This site tabulates national average breeding values of cows and their sires by year of birth. The national average breeding values of sires must be multiplied by one half to make the results comparable with the herd average PTA of sires of cows (see Equation 1). Comparisons between herd average and national average should be made for the same year of birth. This comparison shows only the extent to which the sires of cows in a herd are above or below the national average; it's not possible to determine where a herd would rank among all herds.

Benchmarks for cow PTAs are available from the USDA website listed in the previous paragraph. In addition to sire breeding values, this site shows national averages for cow breeding values by year of birth. Similar tables are available for all dairy breeds and are updated quarterly as new data are added to the system. As genetic base changes are introduced, individual cow PTAs and national averages are updated simultaneously. Comparison of the herd average cow PTA with the national average breeding value requires the conversion between breeding value and transmitting ability shown in Equation 1.

PLANNING A HERD'S GENETIC FUTURE

Planning genetic improvement is a process that should be carried out with due consideration; this is too important to leave to the whims of fate! Two kinds of decision making must be distinguished. Long-term decisions are established at the outset and reviewed periodically but changed infrequently. Short-term decisions are the sire selection and culling decisions that are made almost daily. The long-term decisions set the direction of genetic change and reflect the herd manager's strategy for improving long-term profitability for the dairy enterprise. Genetic improvement itself is a gradual, long-term process; the genetic background of a herd cannot be changed overnight. Through sire selection, only half of the genes in the herd are replaced in each 4- to 5-year generation of cows. One half of the genes in the current herd are from the cows' sires; one quarter of the genes are from the cows' maternal grandsires (e.g., sires of the cows' dams); one eighth of the genes are from the sires of the cows' maternal granddams; and so on. Genetic decisions made more than 10 years ago still affect performance of today's cows; genetic decisions made today will influence performance of the herd 10 years in the future. Both long-term and short-term genetic decisions must be made in this context. Short-term decisions that follow different goals from one year to another will produce a slower rate of improvement toward the desired goal. It is essential to make short-term decisions that are consistently based on pursuit of the long-term objectives.

Long-Term Decisions

The long-term decisions require answers to questions like these:

- What is the relative economic importance of milk volume, fat yield, and protein yield traits in the milk market, now and in the future?
- How important is type in profitability of the herd's economic enterprises? Does the herd plan to sell purebred animals based on a high quality of body conformation? Will surplus animals be merchandised mostly on their production or type characteristics? Is type valued only as it contributes to longer herd life?
- What is the manager's desired balance between increasing revenues (e.g., increasing production) and reducing costs, especially health and reproductive costs?
- What are the current problems in the herd that can be corrected realistically by sire selection?

With answers to these business and strategic questions, the manager can proceed to make rational, long-term decisions for the breeding plan. These decisions include the following:

- Which of the several selection indexes published in the industry is most consistent with the milk market and business strategy of the herd? This index will be used as a tool for screening lists of available bulls and as an aid in selecting individual bulls.
- Does participation in the young sire progeny testing programs of the AI industry contribute to the genetic and business goals of the herd? What are the obligations and benefits of the young sire programs?
- To what extent and under what conditions will AI and non-AI bulls be used? How does each contribute to the genetic and business goals of the herd? What changes in facilities and management system are needed to effectively use AI and non-AI bulls?
- What is the importance of cost control versus long-term genetic improvement? As a business decision, what is the manager's relative sensitivity to semen price differences versus genetic differences among bulls?

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- Does crossbreeding contribute to the business and genetic goals of the herd?
- If breed crossing is not desired, what is the herd's strategy and goal for controlling inbreeding? Would a corrective mating program contribute to the herd's genetic and business success?
- Have sires known to be carriers of specific genetic defects been used in the past? It would be important to avoid using new sires that carry the same defects.

Short-Term Decisions

The most important short-term decisions involve selection of bulls. Outlining a routine process for selecting bulls will enable the manager to stay focused on long-term goals and avoid quick, impulsive decisions that are not consistent with the long-term plan. The elements of this process should include the following:

- Determine the amount of semen needed for the current breeding period and the number of bulls from which to purchase semen. Do not purchase semen too many months in advance of use because genetic evaluations are updated periodically; make selections based on the most reliable information. Do not buy more semen than needed; unused semen is costly!
- Decide on semen sources and whether AI or non-AI bulls are to be used.
- Among all bulls provided by the chosen sources, rank them on the chosen selection index.
- Based on this ranking, select three to five times more bulls than will be purchased; consider only these bulls in further selection decisions.
- Remove from the list any bulls that are carriers of known genetic defects or that have extremely low fertility ratings, extremely high SCS, extremely high calving difficulty, or other extremes that are to be avoided; this step should focus only on the extreme 5 or 10 percent of bulls. Also remove any bulls whose semen cost is so high as to not be warranted by their genetic merit, even as mates to the best cows in the herd.
- Identify bulls with below average calving difficulty ratings; about 40% of the semen purchase should be from this group for mating with nulliparous heifers.
- Identify bulls with high fertility rating and low semen cost to mate with cows having reproductive problems; perhaps 20% of the semen purchase would be from this group. Reduce the list of chosen sires to the desired number considering the selection index and PTAs for type traits, fat or protein percentage, SCS, semen cost, and other desired characteristics.
- Finally, consider reliability of PTA. Among the selected bulls, purchase less semen from those with low reliability (e.g., below 70%) and more semen from bulls with high reliability (e.g., above 80%). Also, reconsider semen cost at this final stage; to reduce average semen cost, consider purchasing less of the most expensive bulls and more of the intermediate- and lower-priced bulls.

The process just described is designed to avoid some of the common errors in decision making. Perhaps most important is that all bulls will be high for the chosen selection index and consistent with long-term goals. Reliability is considered only in the final stage of the decision process; producers often use it as an initial screening tool and place too much importance on it.

Expected Genetic Gain

There are two aspects to forecasting genetic gain. One aspect is the improvement in herd average that can be expected from sire selection. Genetic improvement in the herd average from the current cow generation to the next cow generation can be predicted by Equation 7:

$$\text{Average PTA of service sires} - \text{Average PTA of cows} = \text{Genetic gain} \quad [7]$$

Genetic gain is the increase in performance of herd replacements compared with the performance of their dams. It is not uncommon for this difference to exceed 1000 lb milk, and with careful attention to sire selection, the difference can exceed 1500 lb. Thus, for a typical mating, the daughter's genetic merit will be 1000 lb milk above her dam's genetic merit. The actual production of the daughters will typically be even more than what is predicted by Equation 7 because of improvements in feeding, management, and health care that are made during the 4 or 5 years between the dam's first lactation and the daughter's first lactation.

It is worth noting that herds with previously poor sire selection practices can make greater genetic improvement from one generation to another than herds with previously excellent breeding programs. In Equation 7, notice that if average PTA of service sires is the same for two herds, genetic gain is larger for the herd with lower average cow PTA. The lower herd will realize a greater genetic response from sire selection. Over a period of three or four cow generations—15 to 20 years—a herd with low average genetic merit can approach the genetic level of herds with top breeding programs.

The second aspect of genetic gain deals with the question of whether the response to sire selection is the same in well-managed and poorly-managed herds. Geneticists work from the assumption that genetics and environment operate independently on animal performance. This means that an improvement in feeding, management, or health care will produce the same desired effect in genetically elite animals as it does in animals with average or below average genetic value. It also means that the difference in average performance between daughters of any two bulls is the same in poorly managed herds as in herds with excellent management.

This issue was thoroughly examined using data from Holstein cows throughout the United States that calved in 1979 (Powell and Norman, 1984). Regressions were calculated within herd of cows' milk yields on their sires' PTAs for 10 strata of herd average yield. The strata were increments of 1100 lb milk from less than 12,000 lb to more than 21,000 lb. The results are shown in Fig. 8-6. In the mid-range of herd averages, those from 12,000 to 15,000 lb, a 100-lb difference in the sire's PTA was associated with about a 100-lb difference in daughter milk yield, as expected. Interestingly,

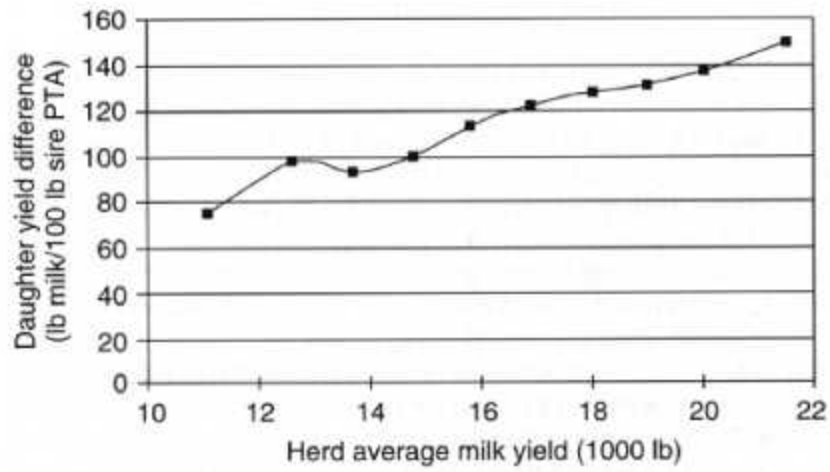

FIG. 8-6 Differences in daughter milk yield per 100-lb difference in sire predicted transmitting ability *(PTA)* milk by level of herd average milk yield. (Adapted from Powell RL, Norman HD: *J Dairy Sci* 67:2021-2027, 1984.)

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in the lowest group of herds, a 100-lb difference in sire's PTA resulted in only a 75-lb difference in daughter performance; and in the highest herds, a 100-lb difference in sire's PTA produced nearly a 150-lb response in production. This evidence indicates that environment and genetics operate in a somewhat multiplicative fashion: Genetic differences between bulls are amplified in herds with high management levels and diminished in low herds. Although two decades have passed since this study was conducted and the top tier of herds at that time are only average by today's standards, the principle still holds. In fact, research continues to demonstrate that heritability increases as breed average increases (Van Tassell et al, 1999).

SOURCES OF IMPROVED GENETICS

Three types of bulls are available and there is a legitimate use for each: AI proven bulls, AI young bulls, and non-AI bulls. Many herds use a combination of two or even all three types of bulls. The decision on which sources are best for a particular dairy depends as much on reproductive management as on genetic improvement goals. Successful use of AI requires careful observation of estrus. Estrous synchronization systems may be used as an aid to managing AI. The producer and veterinarian must collaborate to decide on a reproductive management program, including the decisions to use reproductive management technologies and the types of bulls to be used. Discussion here will emphasize the genetic aspects of these decisions.

Artificial Insemination Proven Bulls

Selecting proven AI bulls is one of the industry's best bargains for improving economic efficiency of dairy herds. The production advantage per lactation of AI bulls over their non-AI counterparts exceeds 1000 lb milk, 30 lb fat, and 30 lb protein with a revenue advantage of $120 per lactation (Animal Improvement Programs Laboratory, 1999a). This is a conservative measure because only the better non-AI bulls are evaluated through the national genetic evaluation system. Depending on how a producer selects natural service bulls, the revenue advantage for above-average AI bulls over nondescript non-AI bulls exceeds $200 per cow per lactation in many cases.

AI bulls are a proven commodity. The buyer acquires a wealth of information along with semen, and this information reduces some of the risks of herd management. Genetic merit of bulls for the most important performance traits has been measured with known reliability. AI bulls are tested for genetic abnormalities. Proven carriers of genetic defects are identified as carriers and bulls that are suspected carriers are tested for the defect and identified as noncarriers if appropriate. A calving difficulty rating is available for most proven AI bulls. A portion of bulls also is rated for fertility. A by-product of managing AI is an accurate record of breeding dates and the ability to project calving dates. This information enhances the manager's ability to manage length of the dry period and properly prepare the cow for calving and the beginning of a new lactation. This information enables the herd manager to avoid problems and make more profitable decisions.

Other advantages for AI include reduced risk of venereal and other infectious disease. Risk of injury from bulls on the farm is completely eliminated by 100% use of AI. It is impossible to place a value on risks such as these. The AI industry offers a wide selection of bulls with proven characteristics; no individual bull has a large impact on the herd. Non-AI bulls can leave many progeny in a herd and these progeny will inherit any undesirable characteristics of the bull; every bull, AI or non-AI, has some undesirable traits. The veterinary and feeding costs used for maintaining natural service bulls can often produce a greater return by milking more cows in place of the bulls.

Artificial Insemination Young Bulls

The AI industry uses well-established methods for developing proven AI bulls. The process begins by mating elite proven AI bulls with cows in the top 1% or 2% of the breed based on PTA. Matings are designed to produce young bulls with the highest possible genetic values. Bulls from these matings constitute the category young AI bulls. Semen is distributed for these young bulls as yearlings. Four years after the initial distribution of semen, daughters of these young bulls complete their first lactations and a PTA is computed based on both progeny and pedigree data. Only the top 10% of these progeny-tested bulls are promoted to active AI status. This final selection step adds around 1000 lb milk to the average PTA of bulls in active AI.

Distribution of semen for the young bulls is done randomly in cooperating herds to achieve an unbiased genetic evaluation of the bull. Usually, only five units of semen per young bull are distributed to each cooperating herd; in most cases this will result in only one milking daughter per herd. Cooperating herds provide data in a timely manner for production, calving difficulty, and other traits; the data are necessary for genetic evaluation of the bull. Herds on the DHI program with excellent record-keeping systems may qualify to cooperate in the young bull progeny-testing program of one or more AI companies. Compensation in the form of credits for service from the AI company is provided to the cooperating herds. Other herds, also, may purchase semen from these young bulls; semen price of young AI bulls is often substantially less than the price of proven bulls.

Genetic merit of the three categories of bulls can be compared directly using PA or PTA. For the most part, only proven AI bulls have genetic evaluations based on PTA; most young AI bulls and non-AI bulls are evaluated on PA as outlined in Equation 5. Research has shown that the PA of young AI bulls is directly comparable with the PTAs of proven AI bulls (Samuelson and Pearson, 1995; Weigel et al, 1995). Although the PAs and reliabilities of young bulls are available, the information is not as widely published as the PTAs of proven bulls. Producers can request this information from the AI firm. The PAs of young AI bulls compares favorably with the PTAs of proven AI bulls. In general the highest PTAs of proven bulls may be above the highest PAs of young AI bulls; however, the PAs of most young AI bulls are higher than the PTAs of lower ranking proven bulls.

Both PA and PTA are unbiased predictors of bulls' true transmitting abilities. Therefore subsequent PTAs of bulls are as likely to increase as decrease while new progeny records enter the evaluation system. The lower reliabilities of PA compared with PTA means that the changes in predicted genetic merit have a larger magnitude for PA than for PTA. In fact, the eventual PTAs of some young bulls will far exceed the PTAs of some of the current proven bulls; unfortunately, there is no way to forecast which young bulls will be the elite sires of the future. Because reliabilities of PA for young AI bulls are only around 30% to 40%, it is important to limit the use of individual young bulls. Several young bulls with high PAs should be used: When their daughters records are incorporated into PTA, their average PTA should not differ appreciably from their average PA, although individual bulls' PTAs may change considerably. By making only a few matings to each of several young bulls, the herd is not being subjected to great risk. A herd that uses young AI bulls may have some of the first daughters of the next generation of high-ranking active AI bulls.

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Non-Artificial Insemination Bulls

In spite of the great advantages for AI bulls, the use of non-AI bulls is clearly a better choice in herds that experience difficulty in managing AI. When labor or skills are inadequate to detect estrus, well-chosen non-AI bulls may lead to a more profitable dairy enterprise. Three considerations are important when selecting non-AI bulls: semen quality, bull health, and genetic merit. Failure to test semen quality subjects the herd to great risk of reproductive failure. Several months can pass before poor fertility of a bull is discovered. Also, it is important to buy bulls that are free of venereal and other infectious diseases. The spread of disease from herd to herd and animal to animal can be a costly risk when using non-AI bulls. Veterinarians and herd managers should insist on disease tests before bulls are purchased to reduce the introduction of costly infections.

Producers must be strongly encouraged to place a high value on genetic merit when selecting non-AI bulls. Too often, buyers of non-AI bulls fail to set discriminating standards for the genetic merit of their bulls. Non-AI bulls of high genetic merit are sons of proven AI bulls with high PTAs out of cows with high PTAs. The PAs and reliabilities for non-AI bulls can be calculated quickly from the PTAs of the bull's sire and dam using Equations 5 and 6. Plenty of bulls are available from sires and dams that meet these standards; producers should insist on these criteria when selecting non-AI bulls. Production of the bull's dam is not a reliable measure of her genetic merit. For example, a cow that produces 20,000 lb milk in a herd that averages 25,000 lb is not a good candidate as the dam of a herd sire. The PTA takes account of all the information available to measure the cow's genetic value. The PTA of a nondescript bull can easily be 1000 to 2000 lb milk below that of a bull with good pedigree data. This translates to a loss of 1000 to 2000 lb milk/lactation in performance of the bulls' daughters. No producer can afford to disregard genetics when selecting non-AI bulls.

INTERNATIONAL GENETIC EVALUATION

The dairy genetics industry is a truly global one. Currently, more than 40% of semen produced in the United States is exported. North American dairy farms increasingly are a marketing target for dairy semen suppliers in other countries. The AI industry is progeny testing more of its young sires in more than one country. Multinational AI companies are another part of this international picture. This international trade in semen has created extensive genetic ties among dairy cattle populations in many countries and has made it possible to accurately compare bulls regardless of country of origin.

The International Bull Evaluation Service, Interbull, coordinates the genetic evaluation of dairy bulls in 25 countries (Interbull, 2000a). The service documents the genetic evaluation methods used in each country and coordinates an active research program on methods for international evaluation. Each country evaluates bulls based on daughter performance within its own borders. Subsequently, each country submits its domestic results to Interbull. The Multiple Across Country Evaluation (MACE) method is employed by Interbull to evaluate all bulls on a standard basis regardless of country of origin (Schaeffer, 1994). Because of sire by environment interaction, the ranking of bulls varies from country to country. Interbull returns the results for all bulls to each contributing country. For each country these results are presented in terms such as breeding value or transmitting ability, same units of measure (kilograms or pounds), and same genetic base that are the norms for that country. By this approach, producers in all participating countries see the international evaluations in terms familiar to each. The program enables producers to correctly compare bulls from their domestic populations with bulls from populations in other countries. These developments began with the yield traits, but over time additional traits, especially health, fertility, and conformation, are being added to the international evaluation procedure.

MATING CONSIDERATIONS

After bulls are selected for breeding the herd, the next set of decisions is how to arrange the matings between cows and bulls. Three aspects of mating are discussed in this section. Controlling inbreeding is the most important consideration in arranging the matings of cows with bulls. The costs of inbreeding in the form of degraded animal performance are subtle but real and should be considered when matings are planned. Corrective mating programs are widely popular among producers. These afford an opportunity to improve the desirability of a few of the type traits. Crossbreeding has not been practiced widely in the dairy industry although it is a predominant practice among commercial producers in virtually all of the other animal industries. This is an opportunity that commercial dairy producers need to explore. Each of these mating systems is discussed separately.

Inbreeding

An inbred animal results from the mating of a cow and bull that are related. The parents of an inbred animal have one or more ancestors in common. In other words, the pedigree of an inbred animal traces back to certain individuals through both the sire and dam. The most important consequence of inbreeding is somewhat impaired performance of inbred offspring. The amount of impairment is called *inbreeding depression*. Impaired performance is most dramatic for genetic defects caused by a single gene, such as BLAD. BLAD animals are homozygous for the defective allele (i.e., they have two copies of the BLAD allele). Carrier animals—those with only one copy of the defective allele—and homozygous normal animals—those with two copies of the normal allele—have normal leukocyte function. Inbreeding reduces the frequency of carriers and increases the frequency of both homozygous types. It is the reduction of carrier animals coupled with the increased number of homozygous defective types through inbreeding that causes the increased frequency of undesirable animals. Often, mild inbreeding leads to the discovery of undesirable recessive alleles such as BLAD. Reduced reproductive performance, increased fetal losses, increased calf mortality, and reduced herd life are all consequences of inbreeding.

Standard animal breeding textbooks, such as Bourdon (2000), outline the process for calculating inbreeding coefficients. The inbreeding coefficient measures the expected percentage of gene loci at which both chromosomes have the same allele inherited from one or more common ancestors through both the sire and dam; such alleles are said to be inherited identically by descent. Table 8-18 shows the inbreeding coefficients that result from a few simple cases of inbreeding. All of these examples involve only a single common ancestor of the parents; pedigrees often involve more than one common ancestor, especially among distant ancestors. When parents have more than one common ancestor, the inbreeding coefficients of progeny will be larger than those shown in Table 8-18.

Inbreeding naturally accumulates in small populations and in populations, like dairy cattle, that are undergoing intense selection. The best cows and the best bulls are both descendants of the best animals from earlier generations. In-

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TABLE 8-18

Inbreeding Coefficients That Result from Matings of Related Parents

Mating parents	Inbreeding coefficient	Common ancestor
Sire × daughter	0.25	Sire is also maternal grandsire
Half brother × half sister	0.125	Paternal grandsire is also maternal grandsire
Grandsire × granddaughter	0.125	Sire is also a great-grandsire on the maternal side
Half uncle × half niece	0.0625	Paternal grandsire is also a great-grandsire on the maternal side
Half first cousin × half first cousin	0.03125	A great-grandsire on the paternal side is also a great-grandsire on the maternal side

evitably, related cows and bulls are mated and produce inbred progeny. Fig. 8-7 shows the average inbreeding coefficients for U.S. Holsteins and Jerseys by year of birth. Inbreeding has increased substantially in recent years (Fig. 8-7). These increases are due to increased intensity of selection and due to the fact that more generations of ancestors are included in the calculation of inbreeding coefficients for recently born animals. These inbreeding calculations are based on pedigree records that trace back to animals born in the 1950s and 1960s.

Inbreeding effects have been measured for several performance traits. Table 8-19 lists recent estimates of inbreeding depression in registered U.S. Holsteins (Smith et al, 1998). Inbreeding depression is the average loss in performance resulting from a 1% increase in the inbreeding coefficient. The table also shows inbreeding depression that would be expected from 12.5% inbreeding and inbreeding depression as a percentage of the breeding value standard deviation. The latter statistic measures inbreeding depression in relation to the opportunity for genetic improvement by selection. When this measure is small, selection can more easily offset the detrimental effects of inbreeding. Two important conclusions emerge from these results: The effects of inbreeding are substantially greater for lifetime measures of performance than single lactation measures, and inbreeding affects yield and herd life to a greater extent than conformation. Clearly, inbreeding should be avoided to produce more profitable animals.

Controlling inbreeding is the most important consideration in arranging the matings of cows with bulls. The goal should not be to avoid inbreeding altogether because that is not attainable. Mating strategies that maximize expected lifetime profit adjusted for inbreeding depression provide greater profits than strategies that maximize profit while placing an upper limit on inbreeding (Weigel and Lin, 2000). In some cases an inbred mating to a genetically superior bull is more profitable than a mating to a bull with lower genetic merit and lower inbreeding; the difference in genetic merit more than offsets inbreeding depression in these matings.

Records for at least two or three generations of ancestors are needed to control inbreeding; this amount of information can be managed manually when planning matings. Additional generations of ancestry are also useful if available because much inbreeding can trace back several generations (Weigel and Lin, 2000). Computer programs are needed to compute inbreeding coefficients for proposed matings when several generations of ancestry are considered. Purebred breeders by virtue of their consistent registration of pedigrees have the best opportunity to manage inbreeding. Participation in pedigree registration programs should be profitable for commercial producers if for no other reason than to plan matings with reduced levels of inbreeding. Herds without records of ancestry almost certainly will make a percentage of matings with somewhat high levels of inbreeding and suffer the consequent impairment of performance.

The easiest recommendation to implement for controlling inbreeding is to avoid matings of cows and bulls that have any parents or grandparents in common. This requires a minimum of pedigree records, avoids the most serious levels of inbreeding, and is an attainable goal. A better goal

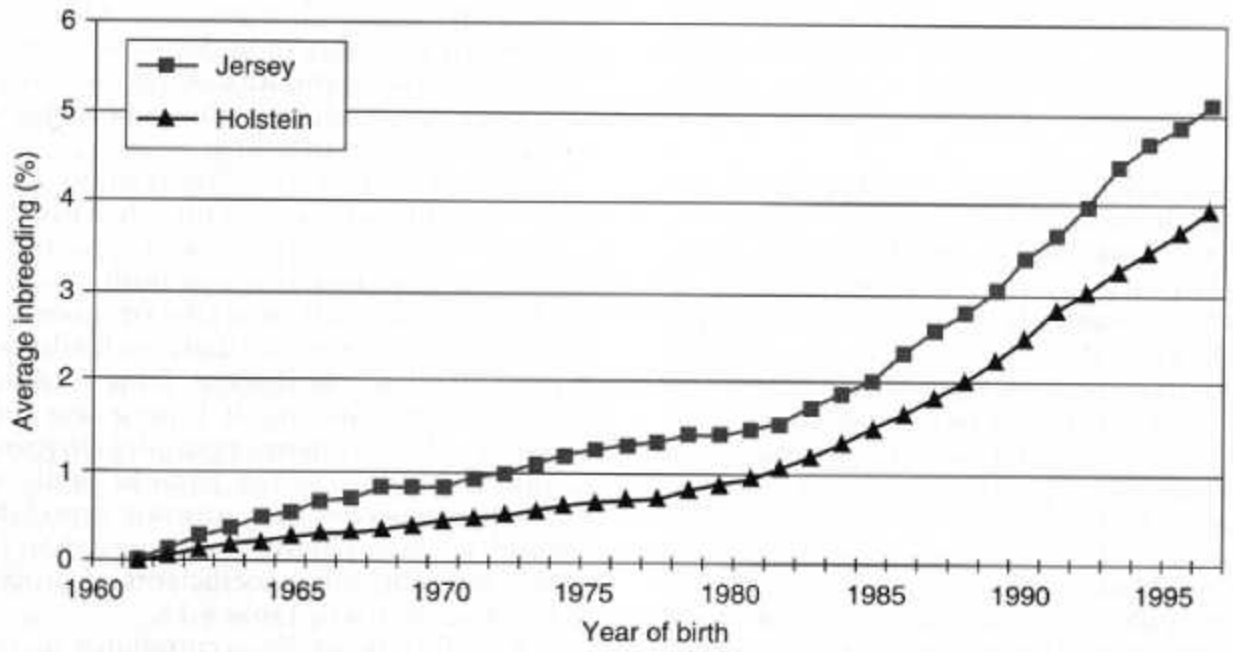

FIG. 8-7 Average inbreeding coefficients for U.S. Holsteins and Jerseys by year of birth. (Data from Animal Improvement Programs Laboratory: Average inbreeding by birth year. Available at http://aipl.arsusda.gov/main/data.html#gtrend [accessed March 6, 2001].)

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TABLE 8-19

Inbreeding Depression for Selected Traits in Registered U.S. Holsteins

	Inbreeding Depression Trait	Standard Per 1% Error	Losses from 12.5% Inbreeding	Inbreeding Depression (% of SD BV)*
RNIOC†($)	−21.78	1.59	−272	6.6
Productive life (days)	−13.07	1.27	−163	6.0
Lifetime days in milk	−10.30	0.96	−129	6.3
First lactation milk (kg)	−37.15	2.95	−464	3.4
First lactation fat (kg)	−1.20	0.09	−15	3.2
First lactation protein (kg)	−1.23	0.10	−15	3.8
Lifetime milk (kg)	−358.41	30.34	−4480	6.4
Lifetime fat (kg)	−13.17	1.12	−165	6.3
Lifetime protein (kg)	−11.41	0.96	−143	6.6
Stature	−0.15	0.02	−1.88	2.7
Body depth	−0.20	0.02	−2.50	4.5
Rump angle	−0.03	0.01	−0.38	1.0
Foot angle	−0.02	0.01	−0.25	0.9
Udder cleft	0.03	0.01	0.38	1.2
Udder depth	0.05	0.01	0.63	1.9
Front teat placement	0.04	0.01	0.50	1.4
Final score	−0.05	0.01	−0.63	2.7

From Smith LA, Cassell BG, Pearson RE: *J Dairy Sci* 81:2729-2737, 1998.
*Inbreeding depression per 1% increase in inbreeding coefficient as percentage of standard deviation of breeding value for the same trait.
†Relative net income adjusted for opportunity cost using milk prices for manufacturing market.

would be to avoid matings that have parents, grandparents or great-grandparents in common. This requires additional records that are sometimes more difficult to obtain and requires more work to plan the matings; this goal ensures lower levels of inbreeding. Considering relationships beyond great-grandparents is difficult without the aid of computer software; when software is available, records of ancestry for many generations can be and should be included.

In the United States, the Animal Improvement Programs Laboratory provides an expected inbreeding of future progeny for bulls. Essentially, this measure indicates the relationship of the bull to cows in the breed. A bull with strong pedigree ties to ancestors with large numbers of descendants will have a high expected inbreeding of future progeny. For herds with good records of ancestry, this measure has little usefulness. Herds without pedigree information can be advised to use bulls with lower values of expected inbreeding of future daughters. This may reduce the chance of inbreeding, but high levels of inbreeding can still occur inadvertently.

Producers who use non-AI bulls must concern themselves with inbreeding when bulls are purchased. Records of ancestry should be obtained with the purchase of a bull. When selecting bulls for purchase, producers should avoid bulls that have parents or grandparents in common with bulls that have been used in the most recent 5 or 10 years. As with the use of AI bulls, matings with natural service bulls should be arranged to control inbreeding.

Corrective Mating

Corrective mating is a popular, widely used service, although little research has been carried out to evaluate the practice. All of the major AI organizations and some breed associations offer corrective mating services. Corrective mating is the practice of mating cows with low PTA for a trait with a bull that is high for that trait. When PTAs aren't available, phenotypic observations are used instead. For example, a cow whose PTA indicates a genetic tendency for rear legs that are too straight would be mated with a bull whose PTA indicates a tendency for daughters to have legs are somewhat too curved as viewed from the side. In other words, corrective mating is designed to produce individuals that are intermediate in genetic value and phenotype for the traits involved in corrective mating. Compared with random mating or some other standard, corrective mating does contribute to producing intermediate types, avoiding extreme types, and improving uniformity of individuals. However, such matings have a limited ability to control variation; producers should not expect corrective mating to produce the kind of uniformity seen in a truck assembly line!

Corrective mating can be useful for some traits, but it clearly does not make sense for others. Most traits have linear economic value: The higher (or lower), the better; each added unit of increase (or decrease) has the same value, regardless of the level of performance. Milk yield, protein percent, and PL are examples of traits with linear economic value. Corrective mating for these traits will increase uniformity but will have no effect on the herd average or economic value of the herd. Uniformity has little merit for traits in this category except when they are uniformly high. It is always important to select sires that have high PTAs for traits with linear economic value.

A few traits have economic values with intermediate optimums (i.e., intermediate values of the trait are more desirable than either high or low extremes). A few of the conformation traits fit this category: teat length, teat placement, udder depth, rear leg set, pin setting or rump angle, and perhaps body size. Animals that are extremely high or extremely low for traits such as these may have more health problems or shorter herd life or require more milking labor than

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animals with intermediate phenotypes. Nonlinear economic values are illustrated in Fig. 8-8 for pin setting and front teat placement. The relative risk of culling is lowest for animals with intermediate scores of these traits; also, relative risk is greatest for both extremely high and extremely low values of the traits. In other words, intermediate values of these traits are most desirable.

Corrective mating can be useful, although it is not critical, for traits with intermediate economic value. The increased uniformity of phenotypes clearly has economic merit for these traits because individuals either above or below the intermediate levels have lower measures of desirability.

Crossbreeding

Crossbreeding is the practice of mating females of one breed with males of another breed. It is widely used by commercial producers of the meat animal species but has been used very little by dairy producers. Recent years have seen a slow growth in use of crossbreeding by dairy managers. Research on crossbreeding among dairy breeds has also been limited. Several crossbreeding trials of modest size were launched in the 1940s and 1950s (Touchberry, 1992). Few important studies have been undertaken since. Modern dairy breeds are vastly different genetically from animals used in those early crossbreeding studies; inferences from those studies to current times would be risky. The growth of interest among producers in crossbreeding and the realization that crossbreeding may offer profitable opportunities for commercial producers is expected to stimulate new research and increased use of crossbreeding in dairy cattle.

In many ways crossbreeding is the genetic opposite of inbreeding: Crossbreeding increases the percentage of genetic loci that are heterozygous (i.e., the two alleles at a locus are different); inbreeding increases the percentage of loci that are homozygous (i.e., the two alleles are identical by descent). For many traits, crossbred animals exhibit higher levels of performance than the average of their purebred parents. *Hybrid vigor* is the term used to describe this advantage in performance of crossbred animals. Inbred animals, on the other hand, tend to exhibit poorer performance than noninbreds. The performance advantage of heterozygous genotypes in comparison with homozygous genotypes was explained in the discussion of inbreeding.

One important criterion for judging the usefulness of crossbreeding is that the performance of crossbreds must exhibit a higher level of performance than the better of the purebreds. For this reason crossbreeding is more often advantageous when the pure breeds are similar in their levels of performance. One reason for the absence of crossbreeding in commercial dairy production is the substantially higher level of milk production by Holsteins compared with other breeds. In a study of Holstein and Jersey crosses on commercial farms in New Zealand, it was shown that the crossbreds produced less milk per lactation than the pure Holsteins and had a lower milk fat percentage than the pure Jerseys. When judged by fat yield, however, the crosses were higher than either pure breed (Ahlborn-Breier and Hohenboken, 1991). As expected, a study of Holstein-Guernsey crosses in the United States found Holsteins produced more milk and fat than the crossbreds. However, survival rates at three ages through second calving were higher for the crossbreds than for either pure breed in this study (Touchberry, 1992).

A well-designed crossbreeding system involving Holstein by Ayrshire-based crosses was conducted in Canada (McAllister et al, 1994). The most striking result in this study was that for various measures of lifetime performance, the crossbreds exceeded the average of the purebreds by 15% to 20%. For single lactation measures of yield traits, the crossbreds were less than 5% above the purebred average. For the lifetime measures, performance of the crossbreds was not significantly different from purebred Holsteins. These results demonstrate that breeding systems should be evaluated on the basis of lifetime performance to allow effects of crossbreeding on survival, reproductive performance, and disease resistance to be expressed.

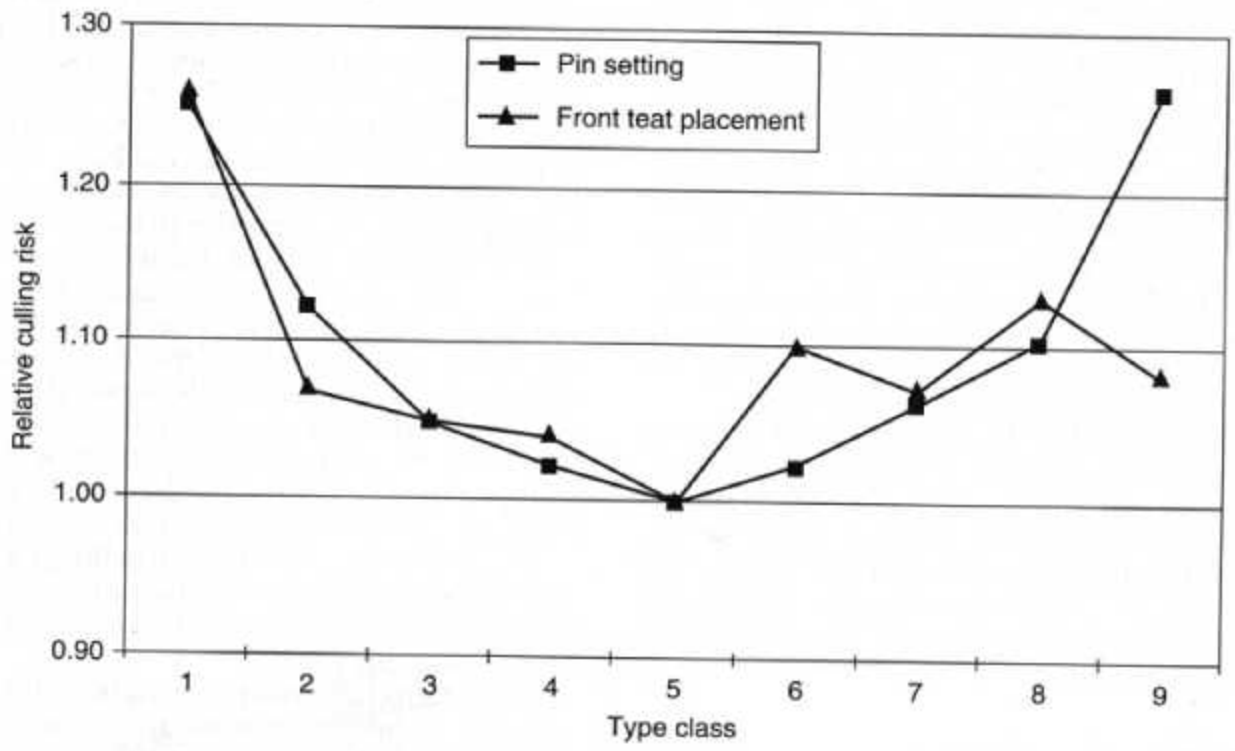

FIG. 8-8 Relative risk of culling by type class for pin setting and front teat placement. (Data from Schneider MDP, Monardes HG, Cue RI: Effects of type traits on functional herd life in Holstein cows. In Proceedings from the International Workshop on EU Concerted Action Genetic Improvement of Functional Traits in Cattle: Longevity, Bulletin 21, International Bull Evaluation Service, 1999, Uppsala, Sweden, 1999, pp. 111-116.)

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Ideally, crossbreeding should be conducted in a systematic manner that exploits to the fullest extent the genetic characteristics of the pure breeds and hybrid vigor in the breed crosses (Bourdon, 2000). The production of F_1 (i.e., two-breed) crosses is an easy first step into a crossbreeding system. The question then becomes how the F_1s should be mated to produce the subsequent generation of animals. Unfortunately, much of the research in dairy cattle has been limited to the study of F_1 crosses. Systems of crossbreeding have been designed in the meat animal species to produce desired types of animals for breeding females, breeding males, and market animals. Much has been learned about the biology of crossbreeding in meat animals that can advance crossbreeding in dairy cattle. However, there are many differences between dairy production and meat production that limit the transfer of information from one industry to the other. Theory cannot predict the ideal crosses and crossing systems; these must be discovered through practice and research.

Rotational crossbreeding systems involving purebred sires and crossbred cows are relatively easy to operate. A two-breed rotation, for example, might begin with purebred cows of breed A. The first cross would be with sires of breed B. The AB females could be mated with sires of either breed, but the breed considered more favorable should be chosen. Thereafter cows would be mated with purebred bulls of the breed opposite that of the cow's sire. Although only two breeds can be involved in the production of the initial crosses, a crossbreeding system can involve three or more breeds. It is known, for example, that a three-breed rotation retains 86%, whereas a two-breed rotation retains only 67% of the hybrid vigor exhibited in F_1 crosses (Bourdon, 2000).

How should a consultant advise a producer who wants to practice crossbreeding with dairy cattle? A critical first step is the choice of breeds. Unfortunately, little research is available to guide a crossbreeding enthusiast on the choice of breeds for dairy production. Because of the substantial advantage of Holsteins over other breeds for the yield traits, Holsteins will be chosen as one of the breeds in most situations. Many factors go into the choice of a second breed; perhaps most important among these is availability of breeding females or semen and average genetic merit of the alternative breeds. The average performance of crossbred animals will be about 5% to 20% above the average of the component breeds. Crossbreeding produces a greater advantage for the survival, reproductive, and lifetime traits than it does for lactation yield. Lactation yields will be around 5% above the midpoint between the parental breeds, survival and reproductive performance is often 10% to 15% above the midpoint, and lifetime production is 15% to 20% above the midpoint (McAllister et al, 1994). Performance measures are readily available for the yield traits, but are sparse for survival and reproductive traits. A fair comparison between pure breeding and cross breeding must be based on lifetime performance.

A second critical decision is the selection of individual animals that are used in the initial breed crosses. These choices should be based on PTAs, selection indexes, and other tools used to select purebred animals. Any breeding system, whether pure breeding or crossbreeding, must be based on animals with high genetic merit.

FUTURE ROLE OF GENETICS IN ANIMAL HEALTH

Genetic improvement for milk production has advanced dramatically during the past 30 years (Fig. 8-1). However, the improvement in production has come at the cost of some loss in virtually every other aspect of animal function. For example, the genetic correlation between milk yield and clinical mastitis is around 0.30, which means that genetic improvement for production is accompanied by a slow increase in incidence of clinical mastitis. Also, improved yield is accompanied by longer days open. Each 1000-lb increase in milk yield was associated with an average increase of 3.2 days open in first lactation and 5.7 days open in second and later lactations (Hageman et al, 1991). A large study of field data found an increase of 5 to 6 days open per 1000-lb increase in milk yield within herd. The smaller effect was observed in high-producing herds and the larger effect occurred in lower-producing herds (Marti and Funk, 1994). The revenues from increased production more than offset these additional costs in health and reproductive performance. However, the current breeding programs are not sustainable over the long term. It is imperative that health and reproductive performance be given increased emphasis in genetic improvement programs. At the current time only rudimentary genetic tools exist for improvement of health and reproduction; the existing genetic evaluations for calving difficulty, SCS, PL, and male fertility are initial steps toward an effective genetic improvement program for health and fertility. Fortunately, industry leaders and researchers in both animal genetics and veterinary science are turning increased attention toward development of genetic programs for health traits.

From a veterinary medicine perspective, genetics can be used as a tool for preventive medicine. The plant industries have used genetic resistance as a method for infectious disease control for many decades, yet this has seldom been applied in the animal industries. Preventive veterinary medicine has focused almost entirely on sanitation, management, and other environmental approaches to disease prevention and control. Genetic improvement for disease resistance can become an effective adjunct to these environmental approaches. Genetic disease resistance would enhance animal well-being, and it would reduce but not eliminate the need for antibiotics and drugs to treat diseased animals. Genetics could become a cost-effective strategy for slowing the development of pathogen resistance to antibiotics, improving food safety, and reducing the economic burden of disease morbidity and mortality.

The advent of genome studies and marker-assisted selection offers a most promising new opportunity to exploit genetics as a tool for disease prevention in livestock (O'Brien et al, 1999). Comparative studies of the genomes of cattle with those of humans, mice, and other species will facilitate the interspecies transfer of knowledge on the genetic basis for disease. Because of the large investment in the human and mouse genome studies, cattle genetics stands to gain heavily from this transfer of information.

DNA markers in cattle and other livestock species have been established at sufficiently close intervals to enable a rough approximation to the location of quantitative trait loci (QTL) for disease resistance (Kappes et al, 1997). The QTL are specific chromosome loci with two or more alleles that confer widely differing levels of disease resistance or susceptibility. Marker genes are ubiquitous, often nonfunctional differences in nucleotide sequence that are relatively easy to assay. Initially, marker genes closely linked to QTL are sought as indicators of genetically resistant or susceptible animals. Ultimately, the aim of research is to discover the QTL that directly cause genetic differences in disease resistance (Holmes, 1994; Soller and Andersson, 1998). Although many genes are involved in genetic disease resistance, the picture is emerging that alleles at a few loci cause major differences in resistance. Genetic resistance is not absolute, however; environmental methods of disease prevention and control will continue to be important in minimizing disease incidence.

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Development of programs for improving genetic disease resistance requires the collaboration of producers, practicing veterinarians, the animal genetics industry, and researchers in animal genetics and veterinary science. Producers need to better understand the economic value of disease prevention, become more aware of disease costs, and be proactive in reducing those costs. Disease record systems for individual animals must become a more important feature of herd management, and these systems must be useful to both the herd manager and practicing veterinarian. In addition, these systems must be standardized to allow aggregation of the records across herds. Centralized databases for disease records must be linked to existing pedigree, production recording, and genetic evaluation systems. Only in the Scandinavian countries does such a system currently exist (Emanuelson, 1988; Ruane et al, 1997). Finally, gene maps and genetic markers must be developed and QTL for disease must be discovered to facilitate selection for disease resistance.

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CHAPTER 9

Health and Production Management of Dairy Calves and Replacement Heifers

A. JUDSON HEINRICHS and OTTO M. RADOSTITS

The successful rearing of dairy calves from birth to weaning depends on a well-managed combination of a healthy dam that calves without difficulty, a clean calving area, and the early ingestion of good-quality colostrum with adequate passive transfer of colostral immunoglobulins to the calf. In addition, clean, dry, and draft-free housing and adequate nutrition following the colostral feeding period up to the time of weaning are important components of a replacement program. Calf morbidity and mortality are perennial problems in all countries where cattle are raised. Most illnesses and deaths occur in the first few weeks of life because of the effects of infection pressure, lack of sufficient colostral immunity, inadequate housing, health care, and nutrition or the effects of adverse environmental conditions.

Today's dairy farms require managers who have skills in many areas, including financial planning, nutrient management, resource management, and, most importantly, dairy husbandry, in order to have a profitable operation. Unfortunately, an area that is neglected on too many dairy farms is the husbandry related to replacement animals. One of the most important aspects of a dairy enterprise is to raise enough replacements with high milk-production potential. Improvement of any herd is possible only when culled cows are replaced by young stock that are properly fed, bred, and managed.

The number of calves dairy farmers need to raise each year to maintain herd size depends largely on herd management and herd health. Approximately 30% of a milking herd is usually replaced each year as a part of normal management. In some herds dairy farmers are replacing over 30% of their cows each year. Assuming 50% of all calves born are heifers, farmers would need to raise 75% of their female calves to maintain herd size. If death losses are substantial, dairy farmers need to raise all heifers that survive and therefore are unable to cull selectively for any herd improvement.

When excellent management is applied with current knowledge and technology, dairy farmers should be able to raise sufficient quantities of well-grown heifers to calve by 24 months of age. Heifers that calve at an earlier age will begin returning their investment at a much earlier date and therefore be more profitable to the dairy farm operation.

Much research has been conducted on proper calf- and heifer-raising practices. In one study in California, dairy farmers were lacking in several areas of management (Goodger and Theodore, 1986). Among these were sanitation of the calving area, insufficient colostrum intake, inadequate veterinary service for young stock, and inadequate use of calf and heifer records. In dairy farms in other areas, the caring of calves was simply a nuisance job, and this was true especially on the larger farms where this job would be assigned to the hired labor. Pennsylvania research by Heinrichs et al (1987b) concluded that many of the farms studied did follow approved calf and heifer management practices, but there were several areas needing improvement, and additional practices involved in calf and heifer management should be followed to reduce age at first calving from 26.6 months. Other Norwegian, Canadian, and U.S. research found similar results relating to calf and heifer management practices (Curtis et al, 1988a; Simensen, 1986; Waltner-Toews et al, 1986d). The extension program in calf and heifer management provided in Pennsylvania reached dairy farmers in addition to individuals in agribusiness, veterinarians, and others who have frequent contact with dairy farmers through many information channels. Most (84.7%) of the farmers learned new information about calf and heifer management during the extension program, and 77.3% indicated that they received all of part of this new information from extension (Heinrichs and Kiernan, 1994).

Over the past 30 years, a large body of literature has accumulated on the anatomical and physiological development of the young calf. Prenatal care of the dam, neonatal behavior, immunoglobulin absorption, nutritional and feeding requirements, and various housing strategies have all been studied under experimental conditions (Waltner-Toews et al, 1986b). Using the literature, supplemented by field surveys and studies of the genetics of calving ease and rural sociopsychology, various authors have attempted to formulate what appears to be scientifically rational dairy calf rearing programs.

In spite of all the information just discussed, the effectiveness of prevention programs in reducing calf morbidity and mortality in the field remains to be demonstrated. We believe sufficient knowledge is available that can be applied at the farm level to manage the health and production of dairy calves so that morbidity and mortality can be maintained at reasonably low levels. Rearing dairy herd replacement animals represents a long-term investment in feed, labor, and other resources to ensure high-quality replacements for the lactating herd. Many of the management-related problems involving nutrition, housing, and health for replacement animals have been studied.

The first section of this chapter outlines the principles of health and production management of dairy calves from birth to weaning. The second section presents the health management of heifer replacements from weaning until first calving and entry into first lactation. It is the responsibility of the veterinarian to educate the producer about factors that are risks to calf health and performance and to determine how those risks can be managed to raise calves successfully and economically. It is the responsibility of the producer to apply the principles of good calf management. It is the responsibility of the manager and veterinarian to monitor calf health and production in the herd and, when necessary, for each to make recommendations to improve performance.

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Health Management of Dairy Calves

The infectious diseases of the digestive and respiratory tracts are the most important diseases of calves from birth up to several months of age. Approximately 75% of the mortality of dairy animals under 1 year of age occurs during the first month of life. This indicates the necessity of giving high priority to a health management system for rearing newborn calves, especially during the first month of life.

CAUSES OF ECONOMIC LOSS IN DAIRY CALVES

Economic losses in dairy calves from birth to weaning are caused by illness, suboptimum performance, and mortality resulting from a number of diseases or inadequacies in production management.

Abortions, Stillbirths, and Congenital Defects

Abortions, stillbirths, and congenital defects account for approximately 2% to 3% of calf mortality and include the common causes of abortion, such as brucellosis and leptospirosis, intrapartum hypoxemia caused by prolonged parturition, and inherited and noninherited congenital defects.

Acute Diarrhea

Acute diarrhea accounts for approximately 75% of the mortality of dairy calves under 3 weeks of age. The most important pathogens associated with diarrhea are enterotoxigenic *Escherichia coli* in calves under 3 to 5 days of age, rotavirus in calves 7 to 10 days of age, corona-virus in calves 7 to 15 days of age, *Cryptosporidia* sp. in calves 15 to 35 days of age, *Salmonella* sp., usually in calves several weeks of age, and coccidiosis (*Eimeria* sp.) in calves older than 3 weeks of age.

Chronic Diarrhea

Inferior-quality milk replacers can cause chronic diarrhea and undernutrition emaciation.

Omphalophlebitis and Arthritis

Omphalophlebitis and arthritis are commonly caused by a mixture of *E. coli, Corynebacterium pyogenes,* and other bacteria.

Septicemia

Coliform septicemia caused by invasive strains of *E. coli* occurs most commonly in calves under 4 days of age that are agammaglobulinemic because of the failure of passive transfer of colostral immunoglobulins.

Enzootic Pneumonia

This occurs primarily in housed calves over 2 months of age. It is caused by infection with respiratory viruses and inadequate ventilation and accounts for about 15% of calf mortality from birth to 6 months of age.

Nutritional Diseases

Suboptimum performance resulting from the inadequate nutrition of calves from birth to 6 months of age is common, but accurate data on the magnitude of the economic losses incurred are not available because dairy producers do not usually monitor calf performance during the first several months after birth. Enzootic muscular dystrophy caused by vitamin E and selenium deficiency occurs in calves 2 to 4 months of age that were raised indoors and then turned out to pasture. An inferior growth rate may have several causes.

Inadequate Dietary Intake of Energy, Protein, Vitamins, and Minerals

This occurs in housed dairy calves fed roughage and grain and in young calves reared on pasture where the quality of the pasture does not meet the nutrient requirements for optimum growth.

Mineral Deficiencies

These can be deficiencies of copper, zinc, or iron, but they are rare.

Postweaning Unthriftiness

This occurs in calves that have been weaned too early, before they begin consuming an adequate amount of dry feed. It also occurs in calves that have been weaned from cow's whole milk or milk replacer onto an inadequate diet. The diet may be inadequate because of poor-quality roughage, low energy and protein content of grains, or inadequate concentration of minerals and vitamins. In calves reared on pasture, the nutrient content of the grass may be inadequate to meet the needs of optimum growth following weaning. Some veterinary aspects of the nutrition of young calves are presented later in this chapter.

Parasitic Gastroenteritis

Parasitic gastroenteritis occurs especially in calves from 2 months of age and older that are being reared on pasture. The common parasites include *Trichostrongylus* sp., *Ostertagia* sp., *Nematodirus* sp., *Bunostomum phlebotomum,* and *Haemonchus contortus.*

Parasitic Pneumonia

Parasitic pneumonia is caused by *Dictyocaulus viviparus* in calves being reared on pasture after about 4 to 5 months of age.

Arthropods

Arthropods include lice *(Linognathus vituli, Haematopinus eurysternus,* and *Damalinia bovis),* ticks, and flies.

Miscellaneous

The miscellaneous category includes abomasal ulcers and poisonings (lead).

EPIDEMIOLOGY OF DAIRY CALF DISEASE

The development and application of the principles of dairy calf health and production management require some knowledge of the descriptive epidemiology of calf morbidity and mortality, achievable targets of performance, risk factors associated with calf morbidity and mortality, and the possible long-term effects of calfhood disease on subsequent performance. In addition, a system of monitoring calf health and production must be established and used to analyze performance and to make recommendations for improvement. All of these are discussed in the following sections.

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Calf Morbidity and Mortality

Dairy calf morbidity statistics are not as reliable as those on mortality. They depend on the producer's clinical diagnosis, whether the animal was treated for the illness, and the tendency of producers not to record every illness event. On the other hand, mortality data are more readily available, because it is easier to count dead calves. Some studies have indicated that the best available data on morbidity are based on treatment rates. In a survey of dairy calf morbidity and mortality in Holstein dairy herds, 20% of live-born calves were treated for diarrhea and 15% were treated for pneumonia before weaning (Waltner-Toews et al, 1986b). In a study of 1171 Holstein heifer calves born over a 2-year period in 26 commercial dairy herds in New York State, the crude incidence rates of diarrhea per 100 calves were as follows for the period of the study: within 14 days of birth (9.9%), diarrhea from 15 to 90 days of age (5.2%), dullness (7.7%), respiratory illness (7.4%) and death (3.5%) (Curtis et al, 1988a).

An analysis of the literature on calf mortality reveals wide variations in the data that are difficult to interpret because no standard time-of-death definition has been used. If abortions are excluded, mortality can be subdivided as follows:

1. Perinatal mortality (stillbirths at more than 270 days of gestation and mortality during the first 24 hours of life)
2. Neonatal mortality (calves born alive that die between 24 hours and 28 days).
3. Older calf mortality (calves born alive that die between 29 and 182 days).

Calf mortality rates from birth to weaning vary from about 1% to 30% and even higher (Curtis et al, 1988a). These mortality rates are misleading because they are mean mortality rates for herds. Mortality rates are known to be skewed to the right because many herds have zero mortality, depending on the length of the survey period. Thus the median mortality rate is a better measure of central tendency than the mean (Curtis et al, 1988a). One of the few studies to measure individual dairy calf mortality was performed in Canada; it was 3.8% for all calves, with a herd median mortality of zero (minimum to maximum, 0% to 67%) (Waltner-Toews et al, 1986b). A survey of dairy farms in Alberta, Canada, found that 60% of all calf deaths occurred at birth, 16% within the first week of life, 21% after 1 week but before weaning, and 3.3% after weaning (Spicer et al, 1994).

In a prospective study of 845 heifer calves born on 30 Holstein dairy farms in Minnesota, the incidence rates for overall morbidity, enteritis, and morbidity resulting from pneumonia were 0.2, 0.15, and 0.10 cases per 100 calf-days at risk, respectively (Sivula et al, 1996b). The average daily rate of gain from birth to 16 weeks of age varied between farms from 0.5 to 1.1 kg/day. The overall mortality rate was 0.08 deaths per 100 calf-days at risk. Enteritis was the most common cause of death followed by pneumonia. Herd management risk factors identified as risk factors for calfhood morbidity and mortality in dairy heifers from birth to 16 weeks of age included the following: feeding a coccidiostat to preweaned calves increased the incidence risk of pneumonia; feeding vitamins A, D, and E to preweaned calves had a protective effect against diarrhea; and management of group pens for postweaned calves in an all-in-all-out flow was associated with farms with an average daily gain above the median for all farms (Sivula et al, 1996a). Calves that required assistance during birth developed diarrhea sooner than calves born without assistance.

In a survey of 407 dairy herds in Virginia reporting 12,300 heifer calf births over a 6-month period, the mortality at birth averaged 1.2%, and the mortality of calves born alive and up to 3 months of age averaged 6.5%. In general, in European countries, the rate of stillborn calves ranges from 3% to 7% and the total mortality rate ranges from 9% to 13% of all calves born. In a 1-year survey of Norwegian dairy herds, the stillbirth rate and calves dying within 24 hours of birth was 2.80% and the overall mortality rate to 30 days was 3.95%, which is extremely low compared with that of other countries. The overall calf mortality rate from birth to 90 days was 18.8%. In a study of Irish dairy herds over a 9-year period, with a total of 9430 calvings, the average incidence of abortion was 1.8%, perinatal mortality (stillbirths and deaths within 48 hours) was 8.37%, and 73% were dead at birth (Mee, 1988).

In typical commercial dairy herds of 50 to 200 lactating cows in North America, the population mortality rate of all live-born calves from birth to weaning ranges from 5% to 10% from year to year and varies from 3% to 30% among individual herds from year to year. Some herds experience no calf mortality over short periods of time (e.g., several months), but on an annual basis some calves die from disease. High losses, up to 50% to 60% of all calves born, have been recorded in large dairy herds with 1000 to 2000 milking cows. This represents a major cause of economic loss on an industry basis.

A survey of calf losses on a Central Dairy Cattle Breeding Station in Bangladesh over a period of 12 years found a mean annual abortion rate of 7.6% and mean annual calf mortality rate from birth to 1 year of age of 13.4% (Debnath et al, 1995). Gastroenteritis was the most frequent cause of death at 30.7%, followed by respiratory diseases at 16.7%. Tuberculosis and foot-and-mouth disease caused 11.3% and 7.6% of the deaths, respectively. Calf mortality was higher in male calves and in calves of exotic breeding and lower birth weight.

The major causes of dairy calf mortality recorded over a 10-year period in an area in Kenya included gastroenteritis, pneumonia, and tick-borne diseases (Mulei et al, 1995). The alimentary and respiratory tract diseases were most common in calves from 1 to 30 days of age. Other causes of death included diseases of the musculoskeletal system (7.0%), septicemia (6.7%), malnutrition (6.1%), cardiovascular system (3.7%), nervous system (3.2%), liver (2.6%), and poisoning (2.6%).

The U.S. Dairy Association (USDA) National Animal Health Monitoring System (USDA, 1996) found rates of preweaned calf mortality in the U.S. dairy industry of 8.4% in 1991 and 10.8% in 1996. No reasons were given for the increase in 1996, which is above the standard errors for those studies of 0.4%. The first national estimates of mortality and morbidity for preweaned dairy heifers in the United States, determined by monitoring 906 herds in 28 states, found that the cumulative mortality incidence risk from birth to 8 weeks of life was 6.3% with a peak of 1.9% during the first week of life (Wells et al, 1996a). Season of birth was significantly associated with cumulative mortality incidence risk, and mortality risk was highest in the periods of January to March and October to December. Cumulative incidence of risk of diarrhea to 8 weeks of age was 24.6% with a peak of 15.4% during the second week of life.

Calves that are surplus to the requirements of the dairy and bull beef industries are slaughtered in New Zealand at 4 to 8 days of age (Biss and Hathaway, 1994). The lesions seen most commonly at slaughter include contamination, wounds, bruising, and omphalophlebitis. The total condemnation rate of carcasses was 2.20%, which decreased to 1.17% following implementation of a national farm-gate quality assurance program and a scientific investigation of traditional meat inspection carcass condemnation criteria.

The weak calf syndrome is a cause of calf mortality. In Northern Ireland it is characterized by the birth of full-term

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calves that either fail to breathe or did not breathe for more than about 10 minutes (Smyth et al, 1996). The cause is uncertain; several different causes have been explored.

Targets of Dairy Calf Health and Performance

Under good management conditions in developed countries, mortality rates according to age groups can be maintained as follows: perinatal mortality, 1% to 3%; neonatal mortality, 3%; and older calf mortality, 1%. In well-managed herds the annual mortality rate of calves under 30 days of age can be controlled at a level below 3% to 5% of all calves born alive and normal. In fact, most well-managed dairy farms do not have a problem with calf disease. However, this does not mean that calf performance is optimum in most dairy herds: it is not. For dairy herds raising their own heifer replacements, the economically important target of performance for the lifetime productivity of the heifer is age at first calving. To achieve optimum milk production for the lifetime of the cow, the heifer should calve for the first time at between 22.5 and 23.5 months of age (Gardner et al, 1988). Decreasing the average age at first calving nearer to 22 to 24 months is an important management practice for which the dairy farmer should strive, and it justifies the maintenance of desirable growth rates of replacement (Heinrichs and Hargrove, 1987).

Effects of Calfhood Disease on Subsequent Performance and Survivorship

Disease is the largest cause of mortality of dairy calves, and the two primary diseases are diarrhea and pneumonia. Pneumonia and umbilical infection occurring in dairy calves reduces body weight gain significantly in the first 3 months of life (Virtala et al, 1996c). In a sample study of New York dairy herds, crude risks for diarrhea, umbilical infection, and umbilical hernia were 28.8%, 14.2%, and 15.1% and the median ages at first diagnosis were 2, 1, and 3 weeks, respectively (Virtala et al, 1996a). The high incidence and long duration of umbilical infection, the finding that diarrhea was the primary cause of death, and the high case-fatality risk for diarrhea during the first week of life suggests that calf caretakers need training in the prevention and clinical management of these diseases. The incidence and case-fatality risk for clinician-diagnoses pneumonia were 25.6% and 2.2%, respectively (Virtala et al, 1996b). *Mycoplasma* sp. and *Pasteurella multocida* together were isolated from affected calves, suggesting a synergistic action.

Canadian research found that calf girth-growth during the first month of age was positively associated with serological titers of total immunoglobulin (total Ig) level. Conversely, girth-growth was negatively associated with a producers' treatment risk of pneumonia and a semimonthly veterinarian clinical examination. Based on radial immunodiffusion measurement, 27% of 325 calves from 17 herds had inadequate levels (total Ig $\leq$800 mg/dl) levels of passively acquired antibodies (Van Donkersgoed et al, 1993).

The effect of early calfhood health status on survivorship and age at first calving, after controlling for the farm effect, has been examined (Waltner-Toews et al, 1986f). Heifers that had been treated for pneumonia during the first 3 months of life were 2.5 times more likely to die after 90 days of age than heifers that had not been treated. Heifers with a calfhood history of being treated for diarrhea were 2.5 times more likely to be sold for dairy purposes than other calves, and heifers that had been treated for diarrhea were 2.9 times more likely to calve after 900 days (30 months) of age than other heifers. Other observations have found that a calving age less than 730 days (24 months) is much more economical to a dairy farmer based on the extra costs and lost production associated with older calving ages (Hoffman and Funk, 1992).

Further research by Waltner-Toews et al (1986g) revealed that the percentage of calves at risk that were first treated for diarrhea peaked during the second week of life (at 8.1%/week) then declined sharply (approaching zero by about 6 weeks). Pneumonia treatment rates peaked at about the sixth week of life (at 2.3%/week) but were more persistent than the treatment rates for scours. Calves were at greater risk of dying during the first week of life than at any time thereafter, and treatment rates for diarrhea and pneumonia were generally lower in spring and summer than during autumn and winter.

Curtis et al (1988a, 1989) followed 1171 Holstein heifer calves on several New York dairy farms. Their findings yielded incidence rates of scours of 9.9% within 14 days of birth, 5.2% from 15 to 90 days of age, 7.7% for calves displaying dullness, and 7.4% for calves with respiratory illness. The only seasonal effect displayed was for scours within 14 days of age, which was higher in winter compared with summer across both years of the study. They also found that the risks of clinical signs were highest in the first week of life, whereas risk of death was highest in the third week of life. This study was taken a step further by Correa et al (1988) by comparing the effects of calf morbidity on age at first calving. Heifers without respiratory illness as calves were twice as likely to calve and calved 6 months earlier compared with those with respiratory illness as calves. What came unexpectedly in this study was that heifers displaying dullness as calves were 1.6 times more likely to calve and calved 2 months earlier when compared to calves without dullness as calves. The researchers speculated that perhaps if dull calves managed to survive to breeding age, they were especially vigorous although no data were available to examine this. Heifers with dullness were dull and listless, had droopy ears, or were off feed. This would be expected to be a problem because of anticipated lower growth rates from inadequate feed intake and unthrifty behavior.

Another study of calfhood health status and subsequent survivorship was conducted among two university herds in Canada by Britney et al (1984). In a study of 460 calves, heifer calves with navel-joint illness within their first 4 months of life exhibited a significantly poorer survival distribution pattern than the other four cohort groups. The other cohorts were identified as those having respiratory, gastrointestinal, septicemic, or other diseases. Navel joint illness is an infection of a calf's navel and is prevalent in some herds. Because of the significantly poorer response of calves with this disease, the researchers concluded that heifer calves contracting navel joint illness cannot survive as well as other calves under such a management program and hence, from a biological point of view, may warrant culling immediately on diagnosis.

Some of the effects just described have now been measured under field conditions, with variable results. Based on the analysis of the records of 34 Ontario Holstein dairy herds, the effects of diarrhea and pneumonia in calves on their subsequent survivorship and age at first calving were assessed. Heifers that had been treated for pneumonia during the first 3 months of life were 2.5 times more likely to die after 90 days of age than heifers that had not been treated for pneumonia, after controlling for the farm effect. Heifers with a calfhood history of being treated for diarrhea were 2.5 times more likely to be sold for dairy purposes than other calves (Waltner-Toews et al, 1986f). Heifers that had been treated for diarrhea were 2.9 times more likely to calve after 900 days of age than other heifers, after controlling for the farm effect. In some studies calfhood morbidity was not significantly associated with subsequent decreased survival

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in the milking herd (Warnick et al, 1997). There was no significant detrimental effect of owner-diagnosed calfhood disease on first lactation milk production; however, affected heifers had higher mortality rates before calving and were less likely to enter the milking herd than unaffected herdmates (Warnick et al, 1995).

Health status of dairy calves and growing heifers has a significant effect on growth rate, especially during the first 6 months of life (Donovan et al, 1998). Season of birth and occurrence of diarrhea, septicemia, and respiratory disease can be significant variables decreasing heifer growth (height and weight). These variables plus farm, birth weight, and exact age when 6-month data are collected can explain 20% and 31% of the variation in body weight and pelvic height growth, respectively, in the growth period from birth to 6 months of age. Septicemia and pneumonia can slow growth by 13 to 15 days (to reach the same weight as healthy calves) during the first 6 months. Diarrhea has a much smaller influence on growth. Passive transfer of colostral immunoglobulins has no direct effect on growth but does influence weight and height growth through its effect on health.

RISK FACTORS FOR DAIRY CALF DISEASE

The epidemiological determinants or risk factors of disease and suboptimum performance that are important in dairy calves under 1 month of age include the *vigor* and health of the calf at birth; the level of *colostral immunity* achieved in the calf; *management practices of the personnel* caring for the calves; *nutritional program*, including the quality of *milk replacers* (if used); herd size; adequacy of the housing and environment, including the hygiene of the calf's microenvironment; and the season of the year (Simensen, 1986). Each of these factors is discussed here and then incorporated into the principles of control and prevention of diseases of calves presented in the second section of this chapter.

The epidemiological interrelationships influencing calf morbidity and mortality are complex. Path analysis of individual calf risk factors for dairy calfhood morbidity and mortality in New York dairy herds indicated that management appears to affect the risk of respiratory disease directly and indirectly (Curtis et al, 1988b). Being born in loose housing increases the risk of diarrhea within 14 days of birth and from 15 to 90 days of birth. Calves of first-calf heifers are at increased risk of respiratory illness, and calves whose dams were vaccinated against *E. coli* are at decreased risk of death. Calves with diarrhea within 14 days of birth, dullness, and diarrhea from 15 to 90 days of age are at increased risk of respiratory illness. Calves that are dull and listless, have droopy ears, and are off feed within 90 days of birth are at the greatest risk of death.

The effects of age and seasonal patterns, association of management with morbidity, and association of management with mortality in dairy herds in Ontario have also been studied (Waltner-Toews et al, 1986c,d,e). The risk of diarrhea peaked during the second week of life; the peak incidence of pneumonia occurred during the sixth week of life. Treatment rates for diarrhea and pneumonia were generally lower in spring and summer than during the autumn and winter. The larger farms had a significantly greater chance of experiencing mortality than did smaller farms, in both winter and summer. Farms that had policies of attending calvings and ensuring that calves received their first colostrum had a significantly lower probability of experiencing winter mortality than farms that did not have these policies. Farms that housed calves in hutches had a lower chance, and those that housed calves in group pens had a higher likelihood of experiencing summer mortality than farms that used individual indoor calf pens.

A survey of factors associated with calf mortality in South Carolina dairy herds revealed an average mortality rate of 19.1% in calves from birth to 6 months of age (Jenny et al, 1981). Mortality to 1 month of age accounted for 84% of the total mortality. Although the survey indicated that several management practices can be related to mortality, it is doubtful that any one practice in itself significantly alters overall mortality or compensates for poor management. However, one poor management practice may outweigh several good practices. It is clear that if dairy producers are to keep calf losses to a minimum, it is essential that sound management programs be implemented, with emphasis on the first month of life. Programs should include as many proven management practices as can be incorporated efficiently and economically, and they should be based on the dairy producer's knowledge, skill, and available resources (Jenny et al, 1981). Calves can be reared successfully under a variety of management conditions. Factors that are considered to have an influence on morbidity and mortality are presented here.

Vigor and Health of the Calf at Birth

Several factors can affect the vigor and health of the calf immediately after birth. If the nutritional status of the dairy female at the time of parturition is adequate, nutritional deficiencies at birth are usually rare. Calves born from dams affected with any disease associated with prolonged anorexia, fever, or septicemia may be weak. Morbidity and mortality in dairy calves are associated with difficult calving in first-calf heifers. Dystocia is affected by several nongenetic and genetic factors, including age and parity of the dam, size of the calf, season of the year, and degree of birth difficulty. In some studies, up to 52% of first-parity dams received assistance in calving (Sieber et al, 1989). Correlations between dystocia and calf mortality have been about 0.7 (Weller et al, 1988). The genetic relationship between calf survival and calving difficulty of Holstein cattle has been examined (Martinez et al, 1983a,b). The high correlation between calving ease and calf survival means that any resultant improvement in calving ease as a result of sire selection or selective breeding is expected to cause improvement of calf survival (Cue and Hayes, 1985). However, there is some evidence that cows with a maternal disposition to easy calving produce daughters with a disposition toward difficult calving. This negative, direct maternal relationship occurs because small calves are born with ease, the small calf becomes a small cow, and the small cow has difficulty calving at early parities.

Prolonged parturition, especially second-stage labor lasting more than 1 hour, can cause postnatal respiratory acidosis in calves, which can adversely affect colostral immunoglobulin absorption (Boyd, 1989; Besser et al, 1990). Risk factors predictive of postnatal acidosis are second-stage labor of more than 1 hour, dystocia requiring traction, and weakness of the calf at birth (Besser et al, 1990).

Colostrum and Colostral Immunity

Calves are born agammaglobulinemic, and the most important factors influencing the health of the newborn calf are the ingestion of liberal quantities of good-quality colostrum within a few hours after birth and the subsequent absorption of sufficient amounts of colostral immunoglobulins within the first 24 hours after birth, when closure occurs. The colostral immunoglobulins that are absorbed provide protection against systemic infections, such as coliform septicemia. The colostral immunoglobulins ingested after closure are not absorbed but remain in the lumen of the intestine and provide local or lactogenic immunity. This is

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particularly important for protection against the rotavirus and coronavirus infections that cause diarrhea in calves after a few days of age.

Some of the absorbed and circulating immunoglobulin G_1 (IgG_1) is transferred back to the intestine and retains significant functional antibody activity in the intestine (Besser et al, 1988a,b). This mechanism accounts for most of the IgG_1 clearance. The concentration of colostral immunoglobulins declines rapidly by 2 to 3 days after parturition to low levels in the postcolostral milk, which makes calves susceptible to viral infections. The mortality rate resulting from diarrhea is much higher in calves with low levels of serum colostral immunoglobulins than in calves with adequate levels. Partial or complete failure of passive transfer of colostral immunoglobulins is a major determinant of liability to neonatal disease and mortality in calves (Gay et al, 1988). When considering the causes of failure of passive transfer of colostral immunoglobulins, the transfer process is affected by the following three major factors.

Formation of Adequate Amounts of Concentrated Immunoglobulin in Colostrum

IgG_1 is concentrated in the colostrum beginning about 4 weeks before calving, and in most cows continues until parturition. IgG_1 is the predominant colostral immunoglobulin, whereas IgM, IgA, and IgG_2 are present in considerably lower concentrations. Dairy cows invariably produce large amounts of colostrum (10 to 20 kg), but the concentration of immunoglobulins varies widely among cows. IgG concentrations are lower in first- and second-parity dams than in later parities, and the concentrations may be lower as the volume of colostrum increases. Calves from first-lactation cows have lower serum immunoglobulin concentrations than calves of older cows. Total immunoglobulin concentration tends to reach a maximum in the third or fourth lactation, almost doubling in amount compared with the first lactation (Devery-Pocius and Larson, 1983). The secretion of immunoglobulin ceases by the time of calving, and over 90% of immunoglobulins transferred at parturition can be expected to appear in the mammary secretion in the first four milkings.

Adequate Immunoglobulin Ingestion

The calf must ingest an adequate total mass of immunoglobulin within a few hours after birth. The concentration of IgG_1 in the colostrum, the age at first feeding, and the volume of colostrum are major factors affecting colostral IgG absorption. IgG concentration in the serum of the calf at 24 hours after colostrum feeding has a positive linear relationship with the IgG concentration in the colostrum. The calf must ingest an immunoglobulin mass of 80 to 100 g to achieve adequate serum levels of immunoglobulins. Natural sucking is the desired method of colostrum intake and is the most efficient, but it is influenced by the sucking drive and the vigor of the calf at birth. Delayed sucking is a major cause of failure of passive transfer in dairy calves. Surveys have shown that 25% to 34% of dairy calves fail to suck by 6 to 8 hours of age, and 18% fail to suck by 18 hours of age. Lack of sucking assistance is also a major contributing factor.

A comparison of three methods of feeding colostrum to dairy calves revealed that, in a dairy herd that allowed its calves to suck naturally, the prevalence of failure of passive transfer (calf serum IgG_1 concentration <10 mg/ml) was greater than 50%, even among calves suckled by cows with above-average concentrations of colostral IgG_1 (Besser et al, 1991). Failure of passive transfer occurred in 19.3% of calves fed colostrum using a nipple bottle and in 10.8% of calves from a herd using tube feeding. The management factor determined to have the greatest influence on the probability of failure of passive transfer in the herds using artificial methods of feeding colostrum was the volume of colostrum fed, since it affected the total amount of IgG_1 received by the calf (Besser et al, 1991). The prevalence of failure of passive transfer can be minimized by artificially feeding all calves large volumes (3 to 4 L) of fresh or refrigerated first-milking colostrum from cows that had nonlactating intervals of normal duration. The administration of colostrum by esophageal tube is an effective method for feeding colostrum to calves too weak or otherwise reluctant to nurse after birth.

One of the major causes of failure of passive transfer in naturally sucking dairy calves is the ingestion of colostrums with inadequate concentrations of immunoglobulins (Gay et al, 1988). There is considerable variation in the intake of colostrum by naturally sucking calves, but the average intake approximates 2.5 L. At this average intake, the colostral immunoglobulin concentration must be 40 g/ml IgG_2 in order to achieve a mass intake of 100 g of Ig. A significant percentage of colostrums do not contain this concentration, and mass intakes are reduced even further in calves that ingest volumes below the average. Passive transfer failure can be minimized by assisting the calf to the udder early in its life and ensuring a long sucking period to the point at which the calf reaches satiation.

The concentration of immunoglobulins in colostrum can be measured indirectly using a hydrometer as a colostrometer (Fleenor and Stott, 1980). The colostrum is placed in a graduated cylinder, and the hydrometer indicates whether the colostrum is superior, adequate, or inferior. This should enable the dairy producer to establish the quality of colostrum prior to feeding and to avoid a first-stage failure in passive transfer of immunity from inferior colostrum. It also allows pooled colostrum to be extended over a greater number of neonates by adjusting the amount fed to a minimum volume that delivers a fixed mass of immunoglobulin.

Systemic Immunoglobulin Absorption

The absorption of immunoglobulins by the intestine into the systemic circulation of the calf is another important factor. Colostral immunoglobulins are absorbed for up to 24 hours after birth in calves, but the maximum efficiency of absorption occurs during the first 6 to 12 hours after birth. This rapid decline in absorption combined with delayed ingestion of colostrum results in failure of passive transfer, which occurs in 10% to 30% of calves, even under ideal conditions. The termination of absorption of colostral immunoglobulins in the calf occurs spontaneously with age at a progressively increased rate after 12 hours postpartum.

The rate and amount of absorption are a function of the concentration of immunoglobulins in the colostrum, the amount fed, and the age at first feeding. Increasing amounts of the colostrum fed (up to 2 L to Holstein calves) increases the amount of absorption. The rate of absorption and maximum absorption is superior in calves that suck their dams. However, up to 42% of calves left with their dams for 1 day after birth fail to either suck or absorb immunoglobulins from colostrum and are hypogammaglobulinemic or agammaglobulinemic. Forced bottle-feeding of calves following sucking for 1 day improves the serum levels of immunoglobulins. To overcome the problem of insufficient absorption of colostral immunoglobulins, it is generally advisable to force-feed colostrum to calves as soon as possible after birth. Calves force-fed colostrum at a dose of 80 ml/kg body weight by stomach tube at 6 hours of age achieve high levels of serum immunoglobulins by 24 hours of age.

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Higher levels are achieved in calves fed colostrum compared with those allowed to suck their dams.

The serum immunoglobulins of newborn calves may vary according to the season of the year. Mean monthly serum IgG_1 concentrations may be lowest in calves born in the winter months (November to May) in temperate climates such as Washington State and Scotland and increase in calves born in the spring and early summer to reach peak levels in September, after which they begin to decrease again (Gay et al, 1983). The opposite has been described for calves born in warmer climates such as Florida, where the highest levels occurred in February and March and lowest levels during the warm summer months.

The serum concentrations of colostral immunoglobulins that are considered adequate in the calf at 24 hours of age and after it has ingested colostrum vary widely, from 5 to 15 mg/ml (Gay et al, 1988). It is important to note that there is no precise level of serum immunoglobulin above or below which resistance or susceptibility to infectious disease exists. The threshold of circulating immunoglobulin concentration associated with increased susceptibility varies from farm to farm; on some farms there is no apparent relationship between immunoglobulin concentration and the incidence or severity of disease. Farms with high calf mortality may have calves with low levels of serum immunoglobulins, but other farms with calves having low levels may have low calf mortality.

Other closely related factors include infection pressure and management practices. An epidemiological study of serum IgG levels in dairy calves from birth to 180 days of age in 300 herds visited during the winter season found that 32% of calves between 1 and 10 days of age were hypogammaglobulinemic (Norheim and Simensen, 1985). There was considerable variation based on age of calf, geographic area, season of the year, parity of dams, method of feeding, and housing factors. The selection of a serum immunoglobulin concentration of 10 mg/ml as a threshold indicator for successful passive transfer is an attainable goal that can be reached with most calves if they ingest a mass of 150 g of IgG_1 (Gay et al, 1988). This means that calves must ingest from 3 to 4 L of colostrum, which may contain 50 to 150 g/L of IgG, within the first day of life. The mean concentration of IgG in fresh colostrum is about 100 g/L IgG, but some colostrums contain only approximately 50 g/L and others contain more than 150 g/L, depending on the interval between calving and sampling and on the volume of the colostrum (Besser et al, 1991).

The variation in immunoglobulin concentration of colostrum among cows can be large. The mean immunoglobulin concentration was 121 g/L at the first milking (7 hours), 61 g/L at the second milking (19 hours), and 24 g/L at the third milking (25 hours) (Fallon et al, 1989). The IgG concentration was less than 50 g/L in 7% of cows, less than 100 g/L in 36%, and less than 150 g/L in 26%. Calves relying on the colostrum with low levels could not attain sufficiently high levels, even with normal levels of colostrum intake. Based on the evaluation of published literature in the United Kingdom and United States over 20 years involving a total of 6566 calves, those with serum levels lower than 10 mg/ml of IgG_1 are four times more likely to die and twice as likely to be affected with disease as calves with adequate levels (White and Andrews, 1986).

Infectious Agents

Knowledge and understanding of the prevalence and virulence characteristics of infectious disease agents in the environment of newborn dairy calves would assist in developing rational disease control programs.

In most cases, the calf is born without any pathogens in its body. However, within minutes after birth, it becomes contaminated with the wide variety of pathogens that are in the immediate environment. It has always been assumed that the level of infectious disease pressure experienced by the newborn calf is directly proportional to the concentration of pathogens in the environment, which includes the bedding or ground surface, walls of the pens, air, and other environmental structures with which the calf comes in contact soon after birth. The dam of the calf and other animals in the immediate vicinity, particularly diarrheic animals or animals ill with other infections, constitute the main source of most pathogens. Calves born into a highly contaminated environment may become infected during birth with enteropathogens carried by their dams or other cows. Enteric pathogens are spread within a herd through the feces of infected animals and all inanimate objects that can be contaminated by feces, including bedding, pails, boots, tools, clothing, and feed and water supplies. Heavily used calving pens can become heavily contaminated with enteric pathogens, such as *E. coli*, *Salmonella* sp., rotavirus, coronavirus, *Cryptosporidium* sp., and *Eimeria* sp. Enterotoxigenic *E. coli* (ETEC) are relatively resistant to environmental factors and can survive for long periods under the right conditions. One serogroup of the organism survived as long as 6.5 months in calf crates contaminated with calf feces (Acres, 1985). The total numbers of bacteria in a calf pen or barn continue to increase as newborn calves are introduced successively into the facility and the facility is continually occupied by animals without depopulation, clean out, disinfection, and period of vacancy (Roy, 1990). This increased occupation time causes a buildup of infection associated with an increasing incidence of enteric disease and suboptimum performance. This can be resolved by moving the animals out of the facility with a clean out and disinfection, followed by a period of vacancy for several days.

The ecology of *E. coli* in market calves fed a milk-substitute diet or in calves reared as dairy cow replacements is dynamic and complex (Hinton et al, 1985a,b). The fecal *E. coli* flora changes continually with time, and an increase in the incidence of resistance among *E. coli* flora can occur independently of oral drug therapy (Hinton et al, 1985a). Multiple resistant strains may appear, and, although their source is uncertain, they may emerge from the use of antibacterial drugs over the years (Hinton et al, 1985a). In calves reared as replacements, there is a continual turnover in the strains forming the majority of fecal *E. coli* (Hinton et al, 1985b). The incidence of antibiotic resistance is low when the calves are a few days of age and housed with adult animals. The antibiotic resistance index (ARI) may then increase during the first week after the animals have been weaned and moved into nursery pens (Hinton et al, 1985b). The ARI then decreases from the third week after weaning to low levels by the time the calves are 5 months of age and the flora is dominated by an increased proportion of sensitive *E. coli*.

ETEC, rotavirus, coronavirus, and *Cryptosporidium* sp.—the four major causes of diarrhea in calves—are responsible for 75% to 95% of enteric infections of calves worldwide. The relative frequency of each of these pathogens varies from farm to farm, year to year, season to season, and country to country. Infections with one pathogen or mixed infections may predominate (Pohjola et al, 1986). The prevalence and incidence of enteropathogens in calves are also age dependent. ETEC affects calves primarily under 2 days of age (Acres, 1985). In contrast, rotavirus, coronavirus, and *Cryptosporidium* affect calves from 3 days of age up to 4 weeks of age. Although these pathogens may be necessary causes of the diarrhea, they may not be sufficient causes. It is important to remember that these pathogens can also be found in

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healthy calves. In some surveys the rotavirus can be found in the feces of up to 50% of healthy calves (Reynolds et al, 1986). In microbiologic surveys of diarrheic and healthy calves, it is common to find mixed infections in diarrheic calves, whereas in healthy calves it is unlikely to find three or more pathogens (Reynolds et al, 1986). In a survey of the fecal samples of diarrheic calves on farms experiencing outbreaks of diarrhea, the rotavirus was the most common enteropathogen found, being excreted by more than half the diarrheic calves (Snodgrass et al, 1986).

Experimentally, there is evidence of synergistic interaction between concomitant rotavirus and ETEC infections of calves about 1 week of age (Runnels et al, 1986). Coronavirus, *Cryptosporidium*, and ETEC were also found in diarrheic calves. Rotavirus was excreted by 18% of healthy calves, coronavirus by 4%, and *Cryptosporidium* by 14%, but no ETEC or *Salmonella* sp. were detected (Snodgrass et al, 1986). In another survey of the prevalence of ETEC in calves in Scotland and northern England, it was found that enterotoxigenic colibacillosis is a major cause of diarrhea in calves less than 3 days old but is not associated with the typical diarrhea problems seen on most farms in calves more than 3 days old.

Enteropathogenic *E. coli* that are not enterotoxigenic but that cause attaching and effacing lesions in the intestines of calves are being recognized with increasing frequency (Wray et al, 1989). These enteropathogenic *E. coli* attach to and efface the microvilli of the intestinal epithelium and resemble the well-known human enteropathogenic *E. coli* (Okerman, 1987). They are associated with dysentery in calves 8 to 21 days of age (Chanter et al, 1986). These strains produce high levels of Shiga-like toxin (Moxley and Francis 1986), attach to the epithelium of the large intestine, and cause degeneration of the enterocytes, which causes dysentery (De Rycke et al, 1987; Schoonderwoerd et al, 1988). These enteropathogens are important zoonoses. Verotoxin-producing *E. coli* serotype 0157H:7 have been incriminated as a causative agent in single cases and outbreaks of hemorrhagic colitis and hemolytic-uremic syndrome in Canada, the United States (Dorn, 1988), England, and Wales (Chapman et al, 1989). Cattle can be a reservoir for the organism, and there is a significant association between an outbreak of diarrhea affecting children in Canada and the consumption of unpasteurized milk (Orskov et al, 1987).

A survey of the prevalence of selected calf pathogens on Holstein dairy farms in Ontario found that 22% of farms had calves infected with *Salmonella* sp., 13% with *Campylobacter jejuni/E. coli*, 41% with enteropathogenic *E. coli*, 19% with rotavirus, and 5% with coronavirus (Waltner-Toews et al, 1986g). The use of nipple feeders for calves was associated with an increased probability of farms having calves shedding detectable fecal levels of *Salmonella* sp., *E. coli*, or one of the two viruses. The use of group pens was associated with increased odds of finding *C. jejuni*. Calves with diarrhea tended to have increased odds of shedding rotavirus and of the presence of *E. coli* with the K99 antigen.

Surveys of the use of antimicrobials prophylactically and therapeutically in calves in dairy herds found that only about 20% of farms administer antimicrobials prophylactically (Waltner-Toews et al, 1986a). About 30% of farms used vitamins prophylactically. There was some evidence that the prophylactic use of antimicrobials was associated with a decreased risk of being treated for pneumonia and of dying, but with an increased risk of being treated for diarrhea.

Several different viruses cause diarrhea and intestinal lesions in calves. The rotaviruses and coronaviruses have been established as major viral agents of diarrhea in young calves (Saif and Smith, 1985). Rotavirus infections cause diarrhea in calves from 5 to 15 days of age. The virus is ubiquitous in the environment of most cattle herds, and serologic surveys have indicated that about 90% of adult cattle have been exposed to the virus and seroconverted. The intestinal tract is the site of multiplication of the rotavirus, and it is excreted in the feces in large numbers, as many as 10^{10} virus particles/g of feces. Because rotaviruses are stable in feces and relatively resistant to commonly used disinfectants, it is extremely difficult to prevent gross contamination of calf barns once infection has been introduced. However, the cycle of rotavirus infection can be broken by thorough cleaning and disinfection of the calf barn (McNulty and Logan, 1983). The mature animal is the source of the virus for the newborn calf, and both calves and adult cattle may excrete the virus for several weeks.

There are at least four serotypes of rotaviruses. The most clinically significant strains in the animal and human populations belong to group A. Those strains belonging to groups B and C and possibly others are known as atypical rotaviruses. There are differences in virulence among the bovine rotaviruses, which may explain the variability in the severity of disease in natural outbreaks, and this must be considered when developing vaccines.

A unique characteristic of rotavirus infection in calves is the short-term nature of the lactogenic immunity provided by colostrum. Newborn calves are protected from the rotavirus only during the first few days after parturition, during which time the colostrum contains a sufficiently high titer of specific rotavirus antibody, which is active in the lumen of the intestine. Calves become susceptible to rotavirus diarrhea at about 5 to 7 days of age. This coincides with a marked drop in colostral immunoglobulins by the third day after parturition and allows for an incubation period of 18 to 24 hours for the disease to occur. The levels of serum and colostral antibody are also lower in first-calf heifers, which may explain the higher morbidity and mortality in their calves.

Bovine coronavirus can cause a severe enteritis in dairy calves. The virus is frequently found in the feces of calves, and a high prevalence of coronavirus antibody has been reported in adult cattle (Collins et al, 1987). In large dairy herds, approximately 50% to 60% of adult cows may shed the virus during the winter months and at parturition, with a smaller percentage during the summer months. Vaccination of the cows with a modified live rotavirus and coronavirus–*E. coli* combination vaccine may cause a decrease in the incidence of shedding at parturition, which may explain the reduction in the incidence of neonatal diarrhea (Collins et al, 1987).

Zoonotic Infections in Dairy Calves

Cattle may excrete certain *E. coli* serotypes associated with human disease, including enterohemorrhagic *E. coli* 0157H:7, which cause bloody diarrhea, hemorrhagic colitis and hemolytic uremic syndrome, and thrombocytopenic purpura. Several strains of enterohemorrhagic *E. coli* associated with enteric disease in humans produce a verotoxin also known as a Shiga-like toxin (Whipp et al, 1994). They do not cause clinical disease in cattle. The most prevalent serotype among human patients in North America, Europe, and the United Kingdom is *E. coli* 0157H:7. Transmission of the organism is thought to occur through the ingestion of uncooked ground beef and consumption of raw milk, although outbreaks have been associated with fresh-pressed apple cider, unchlorinated drinking water, and person-to-person transmission.

Serotype 0157H:7 *E. coli* is classified as an enterohemorrhagic *E. coli* because it causes hemorrhagic colitis, produces a Shiga-like toxin, does not produce either heat-stable or heat-labile toxin (which is characteristic of ETEC), and is not invasive. *E. coli* 0157H:7 is considered the epidemic strain

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because it has been responsible for major outbreaks reported in the United States, Canada, and the United Kingdom.

The prevalence of *E. coli* 0157H:7 in the cattle population is low, but there is a higher prevalence of the organism on dairy farms linked to human illness than on farms representing the general cattle population. The organism resides in the gastrointestinal tract of animals and is shed in the feces of cattle. The excretion period ranges from hours to weeks. Dairy cows are more often implicated in human outbreaks because hamburger contains more meat from dairy cattle than from beef cattle and because they were the source of milk responsible for several well-documented milkborne outbreaks.

In a survey in the United States, the prevalence in dairy heifers and in all cattle was 0.37% and 1.85%, respectively (Whipp et al, 1994). Surveys in cattle in Spain indicate that cattle are reservoirs of verocytotoxigenic *E. coli* (VTEC), which are pathogenic for man (Blanco et al, 1996), and that VTEC and cytotoxic necrotizing *E. coli* (NTEC), which produce cytotoxic necrotizing factor, are normal intestinal flora of cattle.

The organism has been isolated from dairy calves less than 8 weeks of age, and calves were three times more likely to shed the organism after weaning (Garber et al, 1995). Estimates of the prevalence of VTEC fecal carriage among populations of cattle vary considerably. An observed prevalence of 79% for VT1-neutralizing antibodies suggests that exposure to VT1 toxin-producing *E. coli* is widespread in dairy cattle in Ontario (Borman-Eby et al, 1993). In a survey in Germany, 84% of the bovine colostrum samples examined contained Shiga-like toxin activity, which is four to eight times higher than reported isolation rates of Shiga-like toxin *E. coli* from the feces of cattle (Pirro et al, 1995). This suggests that exposure of cows in Germany to these strains of *E. coli* is more widespread than expected from epidemiological studies based on bacterial isolation.

A study of the distribution and characteristics of VTEC isolated from Ontario dairy cattle showed that the prevalence rates in cows and calves were estimated at 9.5% and 24.7%, respectively. The proportion of animals infected on each farm ranged from none to 60% for cows and none to 100% for calves. Of 206 VTEC isolates from 100 dairy farms, few were of serotypes that have been isolated from humans and none were *E. coli* 0157H:7 (Wilson et al, 1992). A case-control study of diarrheal disease in veal calves in Ontario did not identify any VTEC in diarrheic cases or controls (Wilson et al, 1992b). In Ontario, dairy farms with a high prevalence of VTEC infection in calves tended to be small and have open herds Similarly, dairy herds with a high prevalence of VTEC infection among cows tend to be small and more likely to use traditional tie-stall housing systems and bucket milkers than herds with a low prevalence of VTEC infection (Wilson et al, 1993). Shedding of *E. coli* 0157H:7 by infected dairy cattle appears to be transient, and persistence of the organism in the environmental sites is not characteristic (Rahn et al, 1997).

In Washington State, *E. coli* 0157H:7 was found in 0.28% of fecal samples from dairy cattle in 8.3% of herds. Fecal samples, bulk milk samples, and milk filters were negative for the organism. The strain was also isolated from 0.71% of fecal samples from pastured cattle of 16% of herds sampled (Hancock et al. 1994). In a longitudinal study in 14 herds for up to 13 months, the overall prevalence was 1% and 9 of 14 herds were positive (Hancock et al, 1997). Weaned heifers had a higher prevalence (1.8%) than did unweaned calves (0.9%) or adults (0.4%).

In a survey of Wisconsin dairy farms, the herd prevalence was 7.1% and the animal prevalence of 1.8% (Faith et al, 1996). Observations made during the follow-up study suggested that horizontal transmission was an important means of *E. coli* 0157H:7 dissemination on the farms. Drinking water on dairy farms in Wisconsin has also been identified as one source and, because of the failure to detect the organism in a limited number of other environmental samples, indicates that contaminated water may be an important source of the organism on some farms.

In a 15-month study of *E. coli* 0157H:7 in a dairy herd, maximum prevalence at any one visit was 14% in lactating cows, 40% in nonlactating cows, 56% in calves, and 68% in heifers (Mechie et al, 1997). Excretion rates in lactating cows were highest during the first month after calving, falling during lactation and rising to another peak at 7 months prepartum. Between November and May there was no evidence of excretion in any group. The organism was not isolated from milk taken from the bulk tank, but it was isolated from individual milk samples from two animals previously shown to be fecal excreters. All isolates of the organism on that farm were of the same phage type, toxin genotype, and plasmid profile.

ENVIRONMENTAL, HOUSING, AND MANAGEMENT PRACTICES

Nutrition and Management of the Cow During the Dry Period

The vigor and health of the newborn calf at birth can be influenced by the nutrition and management of the cow during the dry period (Quigley and Drewry, 1998). Nutritional and management strategies for dairy cattle are designed to prepare the cow for lactation and to minimize the incidence of metabolic diseases at calving time. Strategies during the dry period should also be used to ensure the birth of a healthy and vigorous calf. Fetal requirements for energy and protein are significant, particularly during the last trimester of gestation. Energy requirements increase 1.3 to 1.5 times maintenance in late pregnancy, which necessitates that formulation of dry cow rations contain sufficient energy to support fetal growth plus maintenance. Protein requirements during pregnancy increase, especially in the last 2 months. Colostrum is a source of immune components and nutrients for the neonatal calf and contains more protein, immunoglobulins, nonprotein nitrogen, fat, ash, vitamins, and minerals than does milk. Because some vitamins do not cross the placental barrier, colostrum is the primary source of these nutrients for the calf after birth. The vitamin E content of colostrum is usually low unless the cow is provided supplementary dietary vitamin E. Calves are born with very low liver reserves of vitamin A and low concentrations of vitamin A (Franklin et al, 1998). Vitamins A and D also do not cross the placenta in significant amounts, and the calf is dependent on the ingestion of colostrum for these vitamins. Dairy producers often inject calves with vitamin A at birth or feed milk replacers with high concentrations of vitamin A (66,000 IU/kg) to ensure that calves are provided with sufficient vitamin A to improve their vitamin A status quickly. However, supplementation of milk with vitamin A from birth to 6 weeks of age did not enhance the plasma vitamin A status or health and immune parameters (Franklin et al, 1998). Selenium readily crosses the placenta. Dry cow diets should be supplemented with vitamins and minerals to improve the quality of colostrum.

Personnel

Those feeding and caring for calves have a marked influence on their health. In a field study, calf survival was highest when the owner's wife fed and cared for the calves, whereas survival was lower when hired labor was responsible for the

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feeding and care of the animals. In 16 large dairy farms in California where the calf mortality rate over a period of at least 2 years on individual farms varied from 3% to 30%, the calf management personnel was the only factor significantly related to the mortality rate. A large study found that dairy operations in which males had primary responsibility for the care and feeding of calves were more likely to have a higher level of mortality (Losinger and Heinrichs, 1997). Herd-management policies directly and indirectly influence the cumulative incidences of morbidity and mortality (Curtis et al, 1993). Path models of the interrelationships between herd-management practices and herd cumulative incidences of calfhood morbidity and mortality have been developed (Curtis et al, 1993). Management practices in Holstein dairy herds associated with higher rolling herd average milk production include calves born in individual areas in buildings, calves hand-fed first colostrum, starter fed to preweaned calves, and ionophores fed to heifers from birth to first calving (Losinger and Heinrichs, 1996a).

Considerably fewer death losses occur on farms in which the owner manages the calves than those in which employees perform the duties. In general, other factors, such as herd size, calving location, and calf housing, were not related to calf deaths in the survey. In a management study that compared management techniques used by various farm personnel that were in charge of calves and heifers (Kiernan and Heinrichs, 1994), they were able to identify several subgroups of people that shared various management techniques. Within the study there were 5 distinct groups based on behavior and management techniques used. Understanding the human behavior can allow the veterinarian to focus education and prevention strategies used for the calf and heifer employees and owners.

This discussion of personnel suggests that—regardless of herd size, housing pen construction, calving site, and many other factors that have been associated with calf mortality—calf rearers and their motivation to raise healthy calves have the greatest influence on calf survival.

Herd Size

As herd size increases, mortality commonly increases. In an expansion program, the total number of cows and milking facilities might be enlarged without a parallel increase in calf-raising facilities and labor. A marked increase in population density commonly causes an increase in the incidence of infectious disease. Outbreaks of infectious disease in calves under 4 weeks of age occur more commonly in large herds (over 100 cows) than in smaller herds and can cause major economic losses because of death, the costs of treatment, and suboptimum calf performance. Dairy herds that house calves in large groups before weaning may need to provide extra care and management to minimize the clinical disease and mortality associated with respiratory disease (Losinger and Heinrichs, 1996b).

In Michigan dairy herds, larger herd size (more than 200 adult cows) was associated with an increased incidence density of calf diarrhea (Frank and Kaneene, 1993).

Season of the Year

Dairy calf death losses increase during midsummer (June, July, August) and midwinter (November, December, January), with mortality rates being 20% higher than those in summer. The risk of death of calves is greatest in their first week of life on most farms. Of all deaths in calves less than 5 weeks of age, 55% occur during the first week of life and 25% to 30% during the second week. In general, the death loss in calves between 5 weeks and 3 months of age is lower than 5%. The season of the year during which the calf barn is occupied by the largest number of calves has a major influence on calf mortality. Many studies have shown that calf mortality is significantly higher during the winter months in colder climates when all calves born may be housed from 2 to 6 months, depending on the length of the winter. This long period of occupation causes an increase in the infection pressure, discomfort because of wet bedding, and perhaps poor ventilation.

During the winter months, increases in calf mortality were associated with cold, wet, windy weather; in summer, greater death losses were associated with hot, dry weather. In general, calf losses in winter were more closely related to the effects of extreme weather than losses in summer. Under Israeli conditions, the critical period for calf mortality is winter, which is cool and rainy. Low temperatures and high humidity are not conducive to calf health and can increase calf mortality. A comparison of calf mortality in two farming systems indicated that the larger farms invested the resources necessary to care for newborn calves in contrast to smaller farms, which did not have the same resources, and mortality was higher.

Relationship Between Housing and Health of Dairy Calves

The provision of a proper environment for calves, in addition to adequate nutrition and other health-related programs, is critical to the success of raising herd replacements. The diagnosis and treatment of sick calves has long been recognized, but the need for effective management of environment to ensure optimum calf health has received much less attention (Bates and Anderson, 1984). On most dairy farms, calves are taken from the maternity area soon after birth and placed in the calf-rearing part of the main barn. Calves raised for herd replacements are commonly maintained in facilities that range from total confinement in narrow, elevated, individual stalls; being tethered along an inside wall of the main barn; group pens; and individual calf hutches to open pastures. The greater the degree of confinement, the more the calves' environment is under the control of the producer, and the less calves are able to make behavioral responses to that environment. Morbidity and mortality rates are usually higher in calves housed indoors than outdoors, but there may be no difference between the health of calves raised in individual pens in an insulated, heated barn and the health of calves raised in outdoor hutches. The increased illness and mortality in calves that are reared indoors is often attributed to a combination of inadequate control of the thermal environment, poor air quality, undesirable relative humidity, inadequate exchange of air, and poor sanitation. However, open sheds and hutches can also become contaminated with common calf pathogens and, when combined with environmental stressors, can cause disease.

Surveys of dairy calf and heifer housing have found that many housing practices are less than adequate (Heinrichs et al, 1987a,b). Dairy producers also recognize calf housing as a problem that is important to the veterinarian, building designer, and manufacturer. Producers who recognize the problem are more receptive to logical and economical solutions through educational programs, new building designs and equipment. Under controlled conditions many different types of calf and heifer housing systems yield satisfactory results when proper management for that housing is undertaken.

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Acute undifferentiated diarrhea of calves under 30 days of age and enzootic pneumonia complex are the two major diseases of concern in housed dairy calves from birth to weaning (Van Donkersgoed et al, 1993). Acute undifferentiated diarrhea is associated primarily with *E. coli*, rotavirus, coronavirus, and *Salmonella* sp. These pathogens are excreted by calves, and the level of contamination in calf pens is dependent on the population density and level of sanitation and hygiene practiced by management. The viruses most commonly associated with enzootic pneumonia include the parainfluenza-3 (PI-3) virus, bovine respiratory syncytial virus (BRSV), and some others, such as the adenovirus. These viruses are considered as primary pathogens and can produce an interstitial pneumonia and atelectasis, which are characteristic lesions. *Mycoplasma* sp. have also been isolated from the lungs of calves with enzootic pneumonia (Kiorpes et al, 1988). Secondary bacterial pneumonia caused by *Pasteurella* sp., *Haemophilus somnus, Actinomyces pyogenes, Streptococcus* sp., and *Salmonella* sp. is a common occurrence in enzootic pneumonia and usually accounts for the severe clinical disease that is characteristic of the advanced stages of the disease.

Sole hemorrhages can be found in female dairy calves examined between 2.5 and 12 months of age (Frankena et al, 1992). The etiology is not well understood, but housing on straw was a preventive factor compared with housing on slatted floors.

The calf is a *homeotherm* and is capable of maintaining a relatively constant body temperature throughout a wide range of ambient temperatures. The internal core temperature of the calf is regulated by the animal's ability to achieve a balance between the heat it produces in metabolism and the heat gained or lost from the environment (Bickert and Herdt, 1985). The calf exchanges heat energy with its surroundings through conduction, convection, radiation, and evaporation. Changes in the immediate physical and thermal surroundings of the calf that affect heat exchange through one or more of its four modes can affect thermoregulation and increase susceptibility to disease.

The *essential environmental* needs of the young calf are *comfort, space,* and *hygiene* (Webster, 1984). The thermal environment, which includes air temperature and air movement, and the physical space, such as the floors and surfaces with which the calf makes contact, must be comfortable. The space available to each calf should at least give it sufficient room to stand up, lie down, turn around, stretch its limbs, and groom itself. It should also provide calves with a reasonable degree of social intercourse. The microbiological environment consists of the floor and wall surfaces, the bedding used, the air quality, the contact the calf makes with other calves, and the utensils and materials used by personnel in feeding and handling the animals.

Many cases of poor health in dairy calves have been traced to inadequate management and ventilation in the calf nursery. Calves reared indoors are commonly affected with pneumonia caused by viruses and bacteria, which may reach high concentrations in the air of poorly ventilated, damp, and cold calf barns (Heinrichs et al, 1994b). Calf barns that are overcrowded, dark, and damp in the winter months and hot and poorly ventilated during the summer months commonly predispose to diseases of the respiratory tract. Unfortunately, in most dairy herds, the emphasis is on the milking cow, and the calf barn traditionally has received low priority, causing uncomfortable rearing conditions that predispose to infectious diseases. Some producers have had so much difficulty raising calves indoors that they have resorted to rearing young calves in calf hutches outdoors. Whereas considerable research and effort have been expended in elucidating the infectious causes of respiratory diseases in calves raised indoors, only a few studies have been done to develop economical and practical methods of providing an optimum environment for calves raised indoors. Enzootic pneumonia of dairy calves often clusters strongly within herds, which may be related to certain risk factors in individual farms (Van Donkersgoed et al, 1993).

The effects of environment and management on mortality in dairy herds were determined by monitoring the herds for 1 year as part of the National Animal Health Monitoring System (Lance et al, 1992). Herd size, days on a nipple feeder, navel disinfection, type of housing, and whether each calf observed with diarrhea was treated with antibiotics were the factor with the most effect on herd mortality. These variables explained approximately 39% of the variation in mortality among herds.

Some common environmental problems in calf barns include the following:

1. Calf-rearing facility not well designed for the size of the herd, ease of cleaning pens, feeding calves, and identification and management of sick calves. Many calf pen areas in the main barn are dark because of lack of lighting, and the attendants do not have a good look at the calves on a daily basis.
2. Overcrowding. This is common in situations in which calves are grouped in pens and calves of different sizes and age groups are raised in the same pens.
3. High relative humidity because of overcrowding, low temperature of incoming air, and lack of supplemental heat. As a result, many calf pens are wet, cold, and uncomfortable, and the calves suffer chronic cold stress.
4. Inadequate movement of air in and out of the building. This can be the result of inadequate inlets, insufficient capacity, or poor location of fans.
5. Rearing calves in close proximity to adult cows. This allows for the spread of pathogens from older, immune animals. A ventilation system that draws air from the adult stock to the calf pens promotes the spread of infectious disease.

The important principles of calf housing include the following:

1. A calf-rearing facility completely isolated from the adult herd.
2. Periodic depopulation for cleaning and disinfection. An ideal system would involve rearing calves in separate groups of stalls or pens to allow serial depopulation, with some of the units being emptied, sanitized, and ready for the next batch of calves. The pens must be designed and located so that they are cleaned easily on a regular basis.
3. An independent and effective ventilation system that is flexible according to the seasonal changes of outside weather. This includes supplemental heat when necessary.
4. Sufficient space for each calf according to its size.
5. An effective feeding system.
6. An adequate lighting system so that each calf can be seen daily.
7. A system that allows regular monitoring of calf performance, such as body weight and height measurements.

Calves can be raised indoors in warm housing facilities that are designed to provide a relatively uniform environment throughout the winter. Attention must be given to ventilation, heating, insulation, controls of ventilation and heating, and management of the system (Bickert and Herdt, 1985). They may also be reared outdoors in cold housing in hutches or other naturally ventilated facilities.

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CALF HOUSING REQUIREMENTS

The following descriptions of an optimum environment for housed calves are offered as guidelines for the veterinarian who may assist the producer in designing a calf barn or evaluating existing calf barns. The reader is encouraged to consult the review literature and general references for more information on details of calf housing (Anderson and Bates, 1984; Bates and Anderson, 1984; Bickert and Herdt, 1985). Veterinarians should seek the assistance of the state or provincial department of agriculture, which usually provides the necessary assistance in designing calf barns and in modifying existing calf barns. Reducing the incidence of pneumonia in dairy calves in a warm calf barn is a complex, multidisciplinary problem (Bantle et al, 1994). Changing the heating and ventilating system in a calf barn can improve the environment and improve the health of the calves, but it may not reduce the incidence of pneumonia. Factors other than simply changing the ventilation system must be considered.

Insulation

For indoor housed calves, adequate insulation of calf barns is normally considered essential to avoid extreme temperature variations in winter and to keep the calf barn cool in summer. The main aim is to use construction materials with a low thermal conductivity in the walls and ceilings. Resistance values (R values) for the various insulating materials are available (Bates and Anderson, 1984). Insulation of the roof is of utmost importance. It is essential to have a vapor barrier, such as a layer of plastic sheeting over the insulating material, to prevent moisture produced in the calf barn from penetrating the insulation and reducing its effectiveness.

Thermal Environment

One of the aims of a well-ventilated calf barn is to keep the calf's body temperature within narrow limits. Newborn calves have a slightly reduced body temperature, rising to 38.7° C (101.6° F) on the first day of life and 38.9° C (102.1° F) on the second day. Thereafter, the body temperature remains at about 38.8° to 39° C (101.8° to 102.2° F) for the first 3 weeks of life. With high levels of feeding there is an increase in body temperature; low levels of feeding cause a reduction of temperature. The environmental comfort zone for calves ranges from 10° to 21° C (50° to 70° F), and achievement of this range depends on the number of calves, their total heat and moisture production, the total surface area and volume of space available, the outside temperature, the insulation properties of the building materials, the type of bedding used (if any), the ventilation rate, and whether supplemental heat is provided. If the environmental temperature of the calf barn goes above the upper limit of the comfort zone, productivity falls progressively. On the other hand, the effect of a drop in temperature below the lower limit of the comfort zone may be slight at first, except for the "wastage" of part of the calf's feed intake in increasing its metabolism to keep warm. The cost of feed intake used as internal fuel is approximately four times the cost of external fuel sources, such as electricity or gas used to keep the calf barn at least at the lower critical temperature.

Calves must be kept on clean, dry bedding and free from cold drafts. The construction and ventilation system of the calf barn depends on the geographic location of the calf barn and on the mean maximum and minimum ambient temperatures experienced in that area. It is much more difficult to ventilate a calf barn during the winter months when the mean outside temperature is −26° C (−15° F) than during other seasons, when the mean outside temperature may be 9.4° C (15° F).

In some areas and under certain circumstances, it may not be economically justifiable to construct or maintain a controlled environment calf house. In the northeast of Scotland, calf house temperatures within the range of 1° to 20° C (34° to 68° F), with relative humidities from 64% to 96%, had no demonstrable effect on calf health and performance (Mitchell and Broadbent, 1973). The extra capital cost involved in a controlled environment type of calf house did not appear to be justifiable in terms of calf health or performance of calves in the northeast of Scotland. The controlled house was insulated, of concrete block construction with an insulated roof, and had fan-assisted ventilation and provision for supplementary heat. The temperature and ventilation were controlled. In the climatic house the salient features were its low-cost wooden frame constructed of exterior grade hard board, without insulation and with no supplementary heat. Ventilation was by ridge outlet and perforated inlets in the upper half of the walls. In both types of calf houses the calves were straw bedded.

Relative Humidity

The generally accepted ideal range of relative humidity for calf barns is 70% to 80%. The relative humidity and inside temperature are interdependent, in that a high relative humidity and low temperature promote condensation on walls and ceilings and ultimately on calves, causing cooling, shivering, discomfort, and a high incidence of respiratory tract disease. Calves give off considerable sensible heat loss and moisture, but the heat production is not sufficient to lower the relative humidity. Thus, under most conditions, supplemental heat is necessary to counteract the additive cooling effect of cold incoming air, which tends to decrease the inside temperature and increase the relative humidity. In Canada and the northern United States, where the mean daytime temperature during the winter months may be as low as −15° C (5° F), owners usually close the air inlets in the calf barns because the incoming air is too cold. However, this is counterproductive because it effectively reduces the ventilation rate to almost nothing, which increases the concentration of aerosol infection. Under these circumstances, supplemental heat is a requirement.

If the relative humidity in the building is high at an abnormally high air temperature, the ability of the animal to dissipate heat by vaporization of water (by sweating or through the lungs) may be seriously impaired, whereas with a low temperature, high humidity can intensify the loss of heat from the animal. A high humidity (over 70% to 80%) at normal or subnormal temperatures almost invariably leads to condensation on the inside surfaces of the building and to damp floors, which may adversely affect the livestock and the building. The humidity is also closely connected with the ventilation of animal barns. The ventilation rate should be adjusted to remove all the moisture produced by the animals. This ensures that the relative humidity of the air remains within the correct range and prevents condensation; in addition, it reduces the danger of cross-infection by respiratory droplets.

Air Intake, Circulation, and Outlets

The amount of air coming into a calf barn must equal that being exhausted. The air is extracted by fans vented through the roof or through the walls or gable ends. The incoming air is introduced through inlets high in the walls or in the ceilings. The movement of air in the calf barn should function to remove excess moisture, dust particles, gases, and infectious agents without creating drafts that increase the loss of heat from the calves and result in chilling. Good

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ventilation, which removes dust and other respirable particles as well as reduces noxious gases, is essential. Undesirable drafts that occur near inlets, doors, and fans must be minimized.

Ventilation Rate and Heating Requirements of Calf Barns

In an inadequately ventilated calf barn, the stagnant air becomes humid and there is a progressive increase in the concentration of dust, ammonia, and other gases. Bacteria and viruses adhere to dust particles, and the combination of these factors predisposes to a high incidence of both acute and respiratory diseases and poor growth rates. In cold climates these effects are most marked in the winter months and lower during the summer months.

Three levels of ventilation must be provided to accommodate seasonal changes that can be achieved with three fans (Bickert and Herdt, 1985). The first fan provides a minimum continuous rate to ensure that moisture removal takes place, even under very cold conditions. As the weather warms, the outside air absorbs less moisture as it moves through the building and a second fan moves more air to keep the relative humidity down to an acceptable level. The second fan is set to turn on when the outside temperature rises above −4° to −1° C (25° to 30° F) and increases the ventilation rate. The third fan is for additional summer ventilation. The sizes of the three fans are determined by the number of calves in the building. The following fan rates are given in cubic feet of air per minute (cfm) for each 45 kg of calf weight (Bickert and Herdt, 1985):

- Fan 1: 15 cfm/45 kg; minimum continuous ventilation with thermostat or timer; total ventilation is 15 cfm/45 kg
- Fan 2: 25 cfm/45 kg; on when outside temperature rises above −4° to −1° C (25° to 30° F); also on when inside temperature rises above 10° C (50° F); total ventilation is 40 cfm/45 kg
- Fan 3: 60 to 100 cfm/45 kg; primarily for the summer; on when inside temperature rises above 13° C (55° F); total ventilation is 100 to 140 cfm/45 kg

If calves are housed during the summer months, the main aim of ventilation is to limit the temperature rise in the calf barn above the outside temperature. This is accomplished by providing sufficient fan capacity. The aim is to provide sufficient ventilation to keep the calf house at or below the upper limit in the optimum temperature range and also to provide a degree of air movement that allows sufficient dissipation of heat to keep the calf cool and comfortable. The ventilation required to meet these standards is based on empiric evidence but, for calves housed in temperate climates during the coldest weather, the minimum ventilation rate recommended is 8 cfm/calf and the maximum for the warmest weather is 50 cfm/calf and even higher in subtropical climates.

Population Density

The floor area requirement per calf depends on whether the calves are to be penned individually or in groups and on the decision of the producer as to what minimum area is acceptable as humane. The smallest area used in veal calf crates for calves up to 300 lb (135 kg) is 10 ft^2 (0.92 m^2), but this area does not allow such calves to turn around after they weigh more than 170 lb (77 kg). Some have suggested a minimum area of 17.5 ft^2 (1.63 m^2) at this weight. At 3 months of age a well-fed calf that is individually penned requires 18 ft^2 (1.67 m^2) of total area or a pen size of 6 × 3 × 5 ft (180 × 90 × 150 cm). Younger calves can be kept in 15-ft^2 (1.39-m^2) pens (5 × 3 ft; 150 × 93 cm), but an area of 12 ft^2 (1.12 m^2) should be considered the absolute minimum for newborn calves. Sufficient space is essential for the expression of play behavior in domestic calves (Jensen et al, 1998).

Sanitation and Disinfection

When large numbers of calves are housed in a calf barn, there is a gradual increase in the population of infectious agents, which creates the potential for increasing the incidence of clinical and subclinical diseases. The infection rate increases with the length of time over which the calf barn is occupied by calves. This buildup of infection can be minimized by depopulating the calf barn and by cleaning and disinfecting the calf pens. This principle has been applied successfully in veal calf operations, in which the previously cleaned and disinfected barn is filled with newly purchased calves within a few days. The calves are fed as a unit for several weeks and then marketed as a unit. This has been called the *all-in, all-out system,* and it has been found to be an effective method.

Cleaning and disinfection of calf pens includes removing all bedding and manure, scraping the floors and walls of pens, washing them with a high-pressure sprayer (300 to 500 lb/in^2), applying a suitable disinfectant, and leaving the pens dry and vacant for at least 2 weeks. The type of disinfectant used is not critical provided that cleaning and washing are scrupulous. Many disinfectants are available, but some of the cheaper ones include 2% sodium hydroxide (caustic soda or lye) and 5% sodium carbonate (washing soda). The reader is referred to a review article on disinfection in veterinary practice. Efficient precleaning and sealing prior to fumigation are of paramount importance.

After having been born in a clean and dry calving pen or area away from the milking herd, the newborn calf should be moved to an isolated pen, stall, or hutch. The major requirement of any calf housing facility is that it be clean, dry, and draft free. Other essentials are that it be located conveniently, be arranged to encourage frequent observation and proper care, and be designed to minimize labor.

Calf Hutches

A proven housing system for the dairy calf in all types of weather is the calf hutch. Hutches should be located in well-drained, protected areas with the open front facing south. A 4 × 8 individual hutch or similar sized solar-type calf hutch is recommended. Only one calf should be placed in each hutch. Clean and disinfect hutches or let them stand upright in the sun for two or more weeks after each calf has been removed. The hutch can be reused in a new location and/or clean the ground area and place fresh fill and bedding under the hutch prior to its reuse.

When sufficient bedding is provided, hutches are comfortable for newborn calves, even when the ambient temperature is well below freezing. Severely cold temperatures (−30° to −18° C; −22° to 0° F) alone are not detrimental to the health and well-being of calves (Rawson et al, 1989a,b). During extremely cold weather the amount of whole milk fed or its equivalent in a milk replacer must be increased by 25% to 50% to a level that approaches the equivalent of 20% of the calf's body weight daily (Anderson and Bates, 1984). If they are not fed sufficient milk during cold weather, calves may suffer clinical cold stress characterized clinically by loss of weight, reduced body temperature, and increased susceptibility to infectious diseases. For calves consuming grain, allowing increased grain intake may supply most of the additional required energy.

Hutches are not a substitute for poor management. They can be labor-saving devices, but each calf must be fed each

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day and monitored for evidence of good health. When properly managed, they can be an excellent system for rearing calves, with a minimum incidence of enteritis and pneumonia. They are sometimes used as an alternative for housing calves during the summer months when the calf barn can be depopulated, cleaned, disinfected, and left vacant for several months. One-piece plastic-fiberglass hutches that are easy to use, clean, and move are now available. Care should be used with some of the translucent types of hutches in warmer climates because the temperature can be very high in these units in the summer months (Lammers et al, 1996b). The provision of supplemental shade for dairy calves reared in commercial calf hutches in southern climates of the United States alters the calf environment but has little effect on overall growth and health (Coleman et al, 1996),

At about 5 to 6 weeks of age, when calves are weaned from milk, they have outgrown individual hutches and must be moved to alternative housing. A super calf hutch measuring 12 × 19 ft, which can house eight calves from 6 weeks of age until they weigh about 180 kg, is available, after which time they are then moved to a heifer-growing facility.

Calf Barns

An alternative to outside portable hutches is a new or existing cold, but well-ventilated, barn with floor level pens. Pens measuring 4 × 8 ft with three solid sides and a slatted opened feeding end should be used. Wire mesh may also be used, but they should be separated by a foot or more to eliminate calf-to-calf nose contact and thus disease transfer. These should be removed to allow for their cleaning and disinfecting and the cleaning of the floor in the barn between calves. If small pens are used, it is necessary to clean the pen during the birth-to-6-week or preweaning period to prevent buildup of manure, urine, and ammonia. Portable pens also allow for use in more than one building or one area of a building as a way to break disease cycles.

Greenhouse-type structures are becoming popular for calf raising. These types of buildings use all of the same principles of a barn, except that with more solar radiation, they are often drier and warmer during the daytime. Ventilation is a key component of these facilities because of the additional solar radiation. These systems often require more management and upkeep than a traditional barn, but are economical to build. Daily temperature fluctuations are a drawback, since they can add stress to newborn calves.

Another popular method of calf housing is the incorporation of calf hutch–type structures in a building with three enclosed sides. This method allows the calves to have outside runs yet allows the operator to be under cover when feeding and caring for the calves.

Newborn calves can be raised successfully inside well-ventilated barns that are kept near outside temperature. It is unwise to try to keep this barn above freezing. Properly fed calves in well-bedded cold barn pens with three solid sides to reduce drafts will grow well in colder climates. An open-front shed or four-sided, naturally ventilated building is recommended. For adequate natural ventilation a continuous opening along the high point of the barn (usually the ridge) should be provided for warm moist air to escape. Provide openings along the eaves to supply fresh air summer and winter. During the winter it may be necessary to shield (not close completely) these openings to prevent cold air from falling directly onto the calves. Plywood covers can be placed over the rear portion of exposed pens for additional protection. It is also important to provide sidewall opening about 4 ft above the floor for additional summer ventilation.

Some existing buildings can be converted to satisfactory cold calf housing if they can be ventilated adequately and cleaned and disinfected properly. If obstructions prevent good natural ventilation, a pressure ventilation system can be installed to ensure a continuous supply of fresh dry air to the calves. A fan and distribution duct should be arranged to blow air along the center of the housing area or along the bank wall. The fan and duct should be sized to change the building air about 15 times an hour during normal winter weather. During extremely cold weather this can be reduced to 10 air changes per hour. A two-speed fan with a thermostat set to reduce it to low speed at about 30° F works well. Care must be taken to ensure that the air coming out of the duct is not directed on animals. If the barn is to be full during hot weather, 50 air changes per hour should be provided.

A good calf-raising facility must minimize environmental stresses on the calf as well as for the operator. Minimization of the environmental stress on the part of the operator encourages a higher level of care that should lead to less sick calves and lower mortality rates.

Weaning pens are an important and often overlooked aspect of a calf-raising system. A small group housing facility for three to five dairy calves should be provided for the immediate postweaning period for at least 1 month. This postweaning area should be a similar housing type and environment to that of the preweaned calf facility and located in a similar area. This allows for regular feeding and observation of this group as part of the feeding of baby calves. Large super hutches located adjacent to a calf hutch area, with an outside yard, can be used in conjunction with hutches. Buildings with inside individual pens should also provide for a 12- × 12-ft group pen for three to five calves. Continuously available frost-free water should always be in any of these pens. Current recommendations are for at least 12 to 18 in of bunk length for each calf, with stanchions or dividers to define the eating position for each calf.

A good, healthful replacement housing system should always meet the following requirements:

- Be clean, dry, and draft free where the animal resides
- For animals up to 3 months old should be isolated from the milking herd and older replacement animals
- Be in a convenient location and arrangement to encourage good care and observation
- Provide for as little manual labor as possible
- Always provide adequate ventilation for the calves

A healthy, strong calf can survive in less than optimum housing conditions in good weather; however, weak calves and harsh weather conditions often cause sick and slow-growing calves. While all the stress on a growing calf is impossible to eliminate, it can be minimized with adequate weaning pens. Sooner or later the calf must adjust to new diets, different surroundings, other calves, and less individual care. The good operator will arrange management methods and facilities to minimize stress on the calf. To make the transition to group living easier on the calf, only a few changes should be made at any one time.

Effects of Rearing Systems on Calf Behavior and Health

There is growing concern about the effects of different calf-rearing systems on calf behavior and health. Some researchers have observed the development of the natural behavior of calves in commercial rearing units selected to represent the range of calf-rearing systems currently in use (Webster et al, 1985a,b). The physiological responses of calves maintained in four types of housing indicate that calves raised in narrow, elevated stalls or individual elevated pens are under more chronic stress than those reared in hutches outdoors or in groups of three to six in

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pens outdoors (Friend et al, 1985). Calves were placed in one of four different housing systems at a few days of age and were open field–tested at about 6 weeks of age. Stall and pen calves performed more actions used in locomotion and defense and engaged in more social behavior than hutch- or group-reared calves when open field–tested (Dellmeier et al, 1985).

PRINCIPLES OF CONTROL AND PREVENTION OF INFECTIOUS DISEASES OF DAIRY CALVES

In general, dairy calf mortality is minimized best by a comprehensive management program that is followed stringently. Published studies have emphasized the interrelationships of a multitude of management factors to calf mortality.

Most common diseases of dairy calves under 1 month of age cannot be prevented totally, and control at an economical level must be the major objective. With good management and disease control techniques, mortality can be maintained economically at a level below 3% to 5% of live-born calves under 1 month of age. A prerequisite for effective, economical control of calf disease is to establish a simple recording system that the producer can understand and use. An effective monitoring system records the following data on a regular basis:

- Dates of birth of each calf
- Dates of illness, diagnosis, and treatments given for each sick calf
- Dates of deaths and results of necropsy, if done
- Growth rate (weight or average daily gain) and height of calf according to age and breed
- Daily amount of milk or milk replacer fed on a weekly basis; nature and amount of grain fed regularly

This information should be collected, collated, and interpreted at each regular herd health visit. The causes of any increases in morbidity and mortality should be explored and recommendations made to implement any necessary changes in management practices.

The most common diseases of calves under 2 months of age are infectious diseases of the digestive and respiratory tracts. The National Dairy Heifer Evaluation Project (USDA, 1994) also found that the diarrhea complex was the most common cause of preweaned calf death (52.2%), followed by respiratory problems (21.3%). This provides a basis for a calf herd health program that should give high priority to the control of these infectious diseases, using the details of the three major principles outlined here.

Reduction of the Degree of Exposure of Calves to Infectious Agents

Infections of newborn dairy calves may occur congenitally or be acquired postnatally. An example of a congenital infection is *Neospora caninum*, which is common in dairy cattle herds throughout the world. The protozoan has been associated with epidemics of abortion and endemic fetal loss in many dairy herds. Congenital infection of dairy calves may represent the main method of transmission in some dairy herds (Dubey and Lindsay, 1996). The life cycle of the organism is unknown but transplacental transmission is the only recognized mode of transmission. Abortion is the only clinical finding in infected cows. Cows of any age may abort from 3 months of gestation to term. Fetuses may die in utero, be resorbed, mummified, autolyzed, stillborn, born alive and clinically affected, or born clinically normal but persistently infected. Congenital infection does not necessarily have a detrimental effect on calf health (Pare et al, 1996), but retention of persistently infected calves contributes to maintenance of infection in the herd. Strategies to control congenital infection include culling of infected seropositive cows and minimizing the introduction of infected replacements into the herd. Control of postnatal transmission is based on the assumption that the protozoan may be transmitted through definitive hosts such as carnivores.

From birth to about 6 months of age, the calf is exposed to different infection pressures. In the first few days of life, the calf is susceptible to ETEC. Between 5 and 15 days of age, and sometimes later, rotavirus and coronavirus infection are the most common causes of enteritis. Salmonellosis may occur at any age but commonly occurs in calves from 1 to 2 months of age; respiratory infections occur most commonly between 2 and 6 months of age. The prevalence of infection of *Cryptosporidia* may be as high as 60% of dairy farms, and farms with multiple-cow maternity facilities and over 100 milking cows are most likely to have calves infected with *Cryptosporidia* (Garber et al, 1994). Therefore every economically feasible management effort should be made to reduce the infection pressure on the calf from birth to several months of age.

The reduction of the degree of exposure to infectious agents begins with the birth of the calf, which should take place in a clean environment. The perineum and udder of dirty cows should be washed shortly before calving. The umbilicus of the calf may be swabbed with 2% tincture of iodine or tied off with nylon thread immediately after birth to control the entry of environmental pathogens. Calves affected with diarrhea should be removed from the main calf nursery and treated in isolation. Well-bedded calving barn stalls, calving corrals in large herds, and pastures provide the ideal environment for the newborn calf. A common traditional practice has been to leave the calf with the dam in the calving pen, allowing it to suck its dam for 2 to 4 days and then transferring it to an individual stall for rearing up to weaning age. This has been a satisfactory system for rearing calves because it allows the dairy producer to minimize exposure of the newborn calf to infectious agents and to provide individual care and feeding during the first month, which is the most critical time in the calf's life. Individual stalls vary considerably in construction, but the most important concerns are that they should be cleaned and disinfected between calves and should be comfortable. In colder climates, where calf hutches are used, the calf may be placed in the hutch within hours of birth, after the calf has been fed a sufficient amount of colostrum and its hair coat has completely dried off.

In large dairy herds, in which the animals are confined during the winter months, diseases such as enterotoxigenic colibacillosis and enzootic pneumonia may be endemic because of the long occupation time of the barns in which adult cows and calves are housed closely together. Disease may become a major problem and may necessitate the construction of a separate calf barn detached from the main barn. With such a system, the calf is born in a box stall in the main barn, force-fed colostrum or allowed to nurse its dam for 2 or 4 days, and then transferred to the calf barn. After the colostral feeding period, newborn calves can also be transferred to calf hutches, which provide an excellent semiisolation rearing facility and help prevent infectious enteric and respiratory diseases.

Regular sanitation and hygiene are of paramount importance in the calf nursery, especially during the first few weeks of life, when the calf is most susceptible to infectious disease. From 2 to 6 months of age, the major concern is the control of respiratory disease, which is dependent on the effectiveness of the ventilation system in maintaining a low level of aerosol infection. The optimum environmental conditions for housed calves were presented earlier.

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Coccidiosis may cause significant economic loss in some dairy herds. Coccidiostats have been used successfully in calf starters to reduce the incidence and severity of coccidiosis in young dairy calves that may be infected as early as 3 weeks of age. Lasalocid has been used in the milk replacer or calf starter to prevent coccidiosis (Quigley et al, 1997). When used in the milk replacer it is superior to its use in calf starters.

Maintenance of High Level of Nonspecific Resistance

The maintenance of high level of nonspecific resistance is dependent on the ingestion of adequate quantities of colostrum within a few hours after birth and on the management and nutrition of the calves.

Management of Newborn Dairy Calves

Keeping dairy calves alive and healthy starts with the maternity area. Herds that use well-bedded box stalls for calving and for the calf during the colostral feeding period have consistently lower calf mortality. Maternity pens should be well bedded and dry. A Michigan study showed a significant relationship between the dry matter content of the bedding and calf mortality. Calf mortality was significantly lower when the bedding in the maternity pen was dry compared with a maternity pen with wet bedding. Straw is considered the ideal bedding; sawdust is questionable because it does not absorb equivalent amounts of moisture. Also, calves tend to eat sawdust, which may precipitate digestive upsets and serve as a vehicle for the entrance of pathogenic organisms into the digestive tract.

The nonspecific resistance of the newborn calf is markedly influenced by the type of housing, the temperature of the calving facilities, the temperature of the calf barn, the person caring for the calves, and whether attendance and assistance are provided at birth. Calf mortality may be higher in herds housed in loose housing than in stanchion-type barns. Calf mortality is also lower in herds that provide heated calving facilities, when the calf house is provided with supplemental heat, and when the calves are cared for and fed by the owner than when managed by hired help. This is particularly important in large herds, in which hired help may be necessary.

Dehorning calves is a common management practice in dairy herds. Cattle that are dehorned represent less danger of injury to the handlers and other animals as well as less disruption by dominant cows during feeding. Some concern has been expressed about the effects of dehorning on production. Electrical dehorning at 8 weeks of age does not affect feed intake and growth rate compared with those of controls.

The practice of collecting and transporting calves from farms to sale yards during their first week of life, and especially during cold weather, has contributed to high mortality from pneumonia and enteritis. Losses in young calves after transportation are highest in those under 2 weeks of age compared with older calves. This suggests that calves should be retained on the home farm for 2 to 3 weeks before being moved. Calves transported from one farm, through sale yards, and to their final destination during the first week of life are prone to disease because of the combined effects of inadequate intake of colostrum; the stress of transportation, starvation, and overcrowding during transportation; and the type of starting feed used in the new premises. Mortality is usually higher in calves started on milk replacers than in those fed milk or skim milk.

One of the greatest needs in the calf industry is the development of an orderly marketing system for newborn calves that are sold from farms and transported to specialized calf-rearing units. The system must consider that, during the first 10 days to 2 weeks of life, the calf is extremely susceptible to the effects of stress, irregular feeding practices, and rough handling, all of which predispose to infectious disease, high mortality, and major economic losses.

Colostrum

Newborn calves have very low concentrations of serum immunoglobulins at birth but have the ability to absorb IgG_1 and other immunoglobulins from colostrum during the first day of life (Besser and Gay, 1993). Many infectious diseases of the newborn calf can be controlled by management interventions to decrease the percentage of hypogammaglobulinemia in calves. Serum IgG_1 concentrations of 10 mg/ml or more are sufficient to protect calves from increased risk of infectious disease in most environments. Successfully obtaining adequate (greater than 10 mg/ml IgG_1) passive serum immunoglobulin concentration in calves requires provision of an adequate mass of immunoglobulin in the colostral meal (approximately 100 g IgG_1/45 kg body weight) and efficient absorption of the colostral immunoglobulin by the calf. Thus the two major requirements are *colostral immunoglobulin mass* and *efficiency of absorption of colostral immunoglobulin*.

Ingestion of liberal quantities of colostrum by the newborn calf within the first 6 hours after birth is the first and most important nutritional requirement of the newborn calf (Gay et al, 1988). The average volume of colostrum ingested by nursing Holstein calves in the first 24 hours of life is reported as 2.4 L (Besser and Gay, 1993). Thus a significant proportion of American Holstein calves fail to ingest an adequate mass of immunoglobulins in management systems that provide colostrum solely by allowing the calf to suck its dam. Control of the amount of colostrum ingested can only be achieved by artificial feeding methods, such as nipple bottle feeders or esophageal tube feeders. Of the artificial feeding methods, the esophageal feeder can ensure that an adequate volume of colostrum is administered early in the absorptive stage. The traditional recommendation for the volume of colostrum to be fed at first feeding is 2 L. If calves refuse to ingest a total of 2 L by nipple bottle, or if calf rearers do not have the time or are impatient to persist with nipple bottle feeding until the required volume is ingested each time by each calf, then the use of an esophageal feeder is recommended. For American Holstein calves, and other breeds of cattle with low colostral immunoglobulin concentrations, attaining protective immunoglobulin concentrations for a high percentage of calves requires large colostrum feeding volumes. Single feedings of *relatively high volumes of colostrum (3.5 to 4 L/45 kg body weight)* cause the lowest percentage of calves with failure of passive transfer by allowing calves fed colostra with relatively low immunoglobulin concentrations to receive an adequate immunoglobulin mass before closure. It is important to note that this volume of colostrum (4 L/45 kg body weight), fed by tube within minutes of birth, causes no apparent discomfort to a minimally restrained calf.

Mixing colostrum from different cows to form pools from which individual calves can be fed may reduce the variation in colostral immunoglobulin concentration as well as provide antibodies to the calf that reflect the antigenic experience of more than just one cow. However, pooled colostrum usually contains immunoglobulin concentrations substantially below the average of the constituent colostra because of the relationships between volume and immunoglobulin concentration. High-volume colostrum supplies can be limited by restricting any individual cow's contribution to the pool to 9 kg.

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The time from birth to feeding is a crucial factor affecting absorption of colostral immunoglobulins by calves (Odde, 1988). The ability of the newborn calf to absorb intact immunoglobulin from colostrum across the intestinal wall to the bloodstream decreases with time, so that any delay beyond the first few hours of life significantly reduces the amount of immunoglobulin absorbed. Delayed nursing may occur because of perinatal asphyxia, environmental conditions, edema of the head and neck because of prolonged parturition, and other managemental factors.

Surveys of calf and heifer management practices in dairy herds have found that husbandry practices for the newborn dairy calf are deficient in many aspects (Heinrichs et al, 1987a,b). The timing and amount of colostrum feeding can be problematic. Field studies have indicated that if dairy calves are left with their dams, up to 25% may not suck within 8 hours and 10% to 25% do not get an adequate amount of colostrum. Newborn dairy calves should be encouraged and assisted to suck their dam within an hour after birth. Assisting the newborn calf to suck to satiation is an effective method of ensuring an adequate intake of colostrum and maximizing the absorption of colostral immunoglobulins (Petrie, 1984). If the calf does not want to suck, it may be necessary to force-feed colostrum using an esophageal feeder tube to ensure that a minimum amount has been ingested early enough. The prevalence of failure of passive transfer in dairy herds could be minimized by artificially feeding all calves large volumes (3 to 4 L) of fresh or refrigerated first-milking colostrum during the first 12 hours after birth, from cows that had nonlactating intervals of normal duration (Besser et al, 1991). Colostrum should be fed for at least 3 days. Absorption of colostral immunoglobulins ceases by 24 hours after birth, but the continued ingestion of colostrum containing adequate levels of specific antibody provides local intestinal immunity against acute undifferentiated diarrhea for as long as the colostrum is fed. Colostrum that is preserved for several days or for up to 2 to 3 weeks is practical, economical, and reliable and may assist in reducing the incidence of infectious diarrheas because of the presence of colostral immunoglobulins, which provide local immunity.

Absorption of immunoglobulins is greatest in the first few hours after birth. In addition, the longer the calf goes without colostrum, the more the chance the calf has of ingesting other harmful pathogens that will also be absorbed. Some of the absorbed and circulating IgG_1 is transferred back to the intestine and retains significant functional antibody activity in the intestine (Besser et al, 1988a,b). This mechanism accounts for most of the IgG clearance.

Passive Transfer Status of Calves. Effectiveness of passive transfer of colostral immunoglobulins depends on the volume of colostrum ingested, the concentration of immunoglobulin in the colostrum, and the time after birth ingested (Gay et al, 1988). Several methods are available to detect failure of passive transfer in calves, including evaluation of total serum protein concentrations by refractometry, zinc sulfate and sodium sulfite turbidity assays, quantitation of serum IgG_1 concentration by radial immunodiffusion, and a commercially available serum glutaraldehyde coagulation test (Garry et al, 1993). Calf mortality can be predicted by using tests for passive transfer of colostral immunoglobulins (Fig. 9-1). The greatest risk of mortality occurs in calves with serum protein concentrations of less than 4.5 g/dl, serum concentrations less than 500 mg/dl, and sodium sulfite test scores below 1 (Rea et al, 1996).

In a study of mortality risk in a large number of dairy calves, 39% of the observed mortality was attributed to inadequate passive transfer (Tyler et al, 1999). Partitioning of the mortality risk associated with failure of passive transfer permits the practitioner to focus on other risk factors that may be responsible for risk factors.

Taking blood from 24- to 28-hour-old calves and measuring the serum total protein can indicate if immunoglobulin absorption has been adequate in the young calf. This measure of the total amount of protein in the serum is highly correlated to immunoglobulin levels obtained and can reflect either the quality of the colostrum fed or the management used in feeding it to the calves. If calves have received

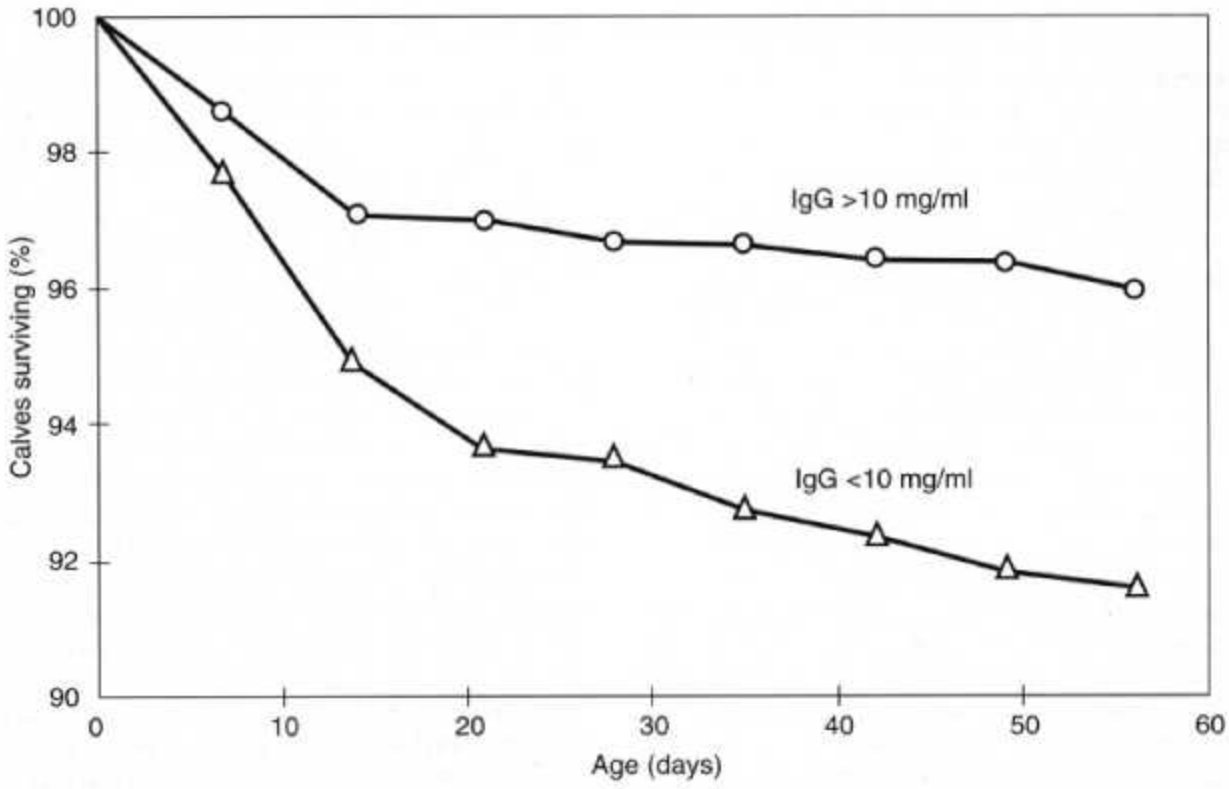

FIG. 9-1 Survival of calves with adequate (>10 mg/ml) or inadequate (<10 mg/ml) immunoglobulin G *(IgG)* concentrations in serum. (From National Animal Health Monitoring Systems: National Dairy Heifer Evaluation Project, 1993. Available at http://www.aphis.usda.gov/vs/ceah/cahm/Dairy_Cattle/ndhep/bamn2.htm [accessed May 17, 2001].)

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adequate levels of colostrum and it is of moderate to excellent quality, the serum total protein levels in the calf should be 5.4 g/dl or greater. When the range falls between 5.0 and 5.4 g/dl, there is a marginal risk for mortality and morbidity. Total serum protein levels less than 5.0 g/dl put the calf at a high risk of health problems.

The goal of a good colostrum program is to achieve high levels of passive antibody protection in calves. It is important to maintain sufficiently high levels until the calves are able to produce their own antibodies. This time period is about 21 to 28 days of age. Calves that have a higher stress of pathogens may have a need for a higher level of passive antibody protection from colostrum.

A study conducted in 1991 and 1992 by the USDA (National Dairy Heifer Evaluation Project) (Heinrichs et al, 1994a) found that calves with lower levels of total serum protein in their blood at 24 to 48 hours of age were twice as likely to die within the first 56 days of age. There are a variety of reasons why calves do not get enough colostrum antibodies, but the quality and quantity of colostrum fed are two very important reasons. It has always been recommended to feed calves 2 to 3 quarts of colostrum within 1 hour after birth and another 2 quarts within 12 hours so that some additional antibody absorption can occur from this second batch of colostrum. On many farms today, because of increased stresses and more pathogen exposure, it is recommended that calves receive 3 quarts of colostrum and some strive for 4 quarts.

One area of controversy is whether all 3 or 4 quarts should be given in one or two feedings. The main question is, does one feeding versus two affect IgG absorption by the calf. A recent study conducted by researchers from North Carolina and Tennessee (Hopkins and Quigley, 1997) showed that providing colostrum at a single feeding did not affect dry matter intake, weight gain, or the serum IgG concentration at 48 hours of life compared with a split feeding. High-quality colostrum can be fed at either one or two feedings without affecting IgG absorption. Feeding adequate amounts of colostrum soon after the calf is born can help offset the environmental and pathogenic challenges that face the newborn calf during the first few weeks of life.

In situations in which calves cannot or do not drink the desired amount of colostrum, an esophageal feeder can be used. This device represents a way of getting colostrum into a weak calf without a great deal of struggling.

A study with data from the National Dairy Heifer Evaluation Project (Wells et al, 1996b) was done on the risk factors for calf mortality and morbidity. Most dairy farmers feed colostrum with a bucket, 2 quarts or less within 6 hours (31.2% of the calves in the United States), 2 quarts or less within 6 or more hours (16.4% of calves), or nursing within 6 hours (22.4% of calves). A small percentage of calves in the United States were fed with esophageal feeders as a means of feeding first colostrum. Bucket-fed calves being fed 2 quarts or more had similar odds of mortality within the first 21 days of life. Calves that were allowed to nurse had just slightly greater odds of mortality. Most of the groups of calves fed first colostrum with an esophageal feeder had much higher odds of mortality within the first 21 days of life. The group fed using an esophageal feeder within 6 hours of birth and getting between 2 and 4 quarts were 5.7 times more likely to die than the average calf in the survey, and the group fed 4 quarts or more with an esophageal feeder at 6 or more hours of age were 9.7 times more likely to die. Thus the esophageal feeders, while being a convenient method of feeding newborn calves, should not be used as an alternative to a bucket or bottle unless necessary.

Delayed intake of first colostrum after birth can decrease serum immunoglobulin concentration by about 2 mg/ml for each 30-minute delay (Rajala and Castren, 1995). High colostral immunoglobulin concentrations do not ensure high serum immunoglobulin concentrations among calves that suck naturally, and when calves are left with their dams after birth, they should be assisted so that they suck their dams as soon as possible to ensure the acquisition of high serum immunoglobulin concentrations. Whether the calves are left with their dams for up to 5 days after birth, or if they are weaned immediately after birth and fed colostrum from open pails, the most important factor is the amount of colostrum ingested within the first several hours after birth (Besser and Gay, 1993). Jersey calves allowed to nurse their dams for 3 days and then placed in hutches achieved optimum transfer of passive immunity (Quigley et al, 1995).

Colostrum Quality. Only the first milking of colostrum after calving should be considered for feeding to calves for immunoglobulin transfer. Second or later milkings of colostrum contain considerably lower immunoglobulin concentrations and are unsuitable for transfer (Table 9-1). Colostra from cows that have been premilked or that leak milk before first milking are also not suitable for first feeding of calves. Some breeds of cattle, including American Holsteins, produce colostra of relatively low immunoglobulin concentration. In a study of over 900 first-milking colostra from American Holstein cows, only 29% of the colostra contained a sufficiently high concentration of immunoglobulin to provide 100 g of IgG_1 in a 2-L volume. The equivalent percentages for a 3- and 4-L volume of feedings were 71% and 87%, respectively.

The specific gravity of colostrum is linearly related to colostral immunoglobulin concentration. The specific gravity cut-off point appropriate for selection of colostra for feeding on a given farm depends on the volume of colostrum routinely fed to each calf. For example, if 2 L of colostrum are fed to each calf, an IgG_1 of 50 mg/ml is needed to provide the calf with 100 g of IgG_1. The cut-off point recommended to distinguish moderate from excellent colostrum was 1.046 (Fleenor and Stott, 1980). While most colostra with a specific gravity of less than 1.046 g/ml have IgG_1 concentrations of less than 50 mg/ml, the fact that more than half the colostra with IgG_1 concentrations of less than 50 mg/ml have a specific gravity greater than 1.046 limits the value of this test. Categorizing colostra using a cut-off point value higher than 1.046 reduces the percentage of selected colostra with less than 50 mg/ml IgG_1 and thereby increases the benefit of selecting colostra by specific gravity.

At temperatures less than 68° F colostrometer readings overestimate immunoglobulin concentration; readings underestimate immunoglobulin concentration of colostrum over 68° F (Mechor et al, 1991, 1992). Actual immunoglobulin measurements of colostrum are time-consuming procedures and impractical for routine samples.

The concentration of antibodies in colostrum varies because of a variety of factors such as the disease history and exposure of each individual cow, the volume of colostrum produced, the season of year (Gay et al, 1983), nutrition of the cow, and the breed, to name the most important ones. Research has shown tremendous variation in colostrum immunoglobulin concentration. Values for IgG can easily range from 20 to 100 g/L of IgG. Cows that have been exposed to a greater number of disease organisms and pathogens will produce a greater number and variety of immunoglobulins than those exposed to fewer organisms. These immunoglobulins have various degrees of specificity, and therefore each different organism that the cows are exposed to tend to increase the IgG content of the subsequent colostrum produced by the cows. When fixed volumes of colostrum are fed to neonatal dairy calves, higher serum

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TABLE 9-1

Colostrum of Bovine Composition

Item	Milking Number 1	2	3	Milk
Specific gravity	1.056	1.040	1.035	1.032
Solids (%)	23.9	17.9	14.1	12.9
Protein (%)	14.0	8.4	5.1	3.1
Casein (%)	4.8	4.3	3.8	2.5
IgG (mg/ml)	48.0	25.0	15.0	0.60
Fat (%)	6.7	5.4	3.9	3.7
Vitamin A (μg/L)	2950	1900	1130	340
Vitamin D (IU/g fat)	0.9 to 1.8	—	—	0.4
Riboflavin (μg/ml)	4.8	2.7	1.9	1.5
Choline (mg/ml)	0.70	0.34	0.23	0.13

From Foley JA, Otterby DE: *J Dairy Sci* 61:1033-1060, 1978.

IgG_1 concentrations are achieved with high Ig colostrum (60 mg/ml) than with low Ig (24 mg/ml) colostrum (Morin et al, 1997).

IgG_1 is concentrated in the colostrum beginning about 4 weeks before calving, and in most cows continues until parturition. IgG_1 is the predominant colostral immunoglobulin, whereas IgM, IgA, and IgG_2 are present in considerably lower concentrations. Dairy cows invariably produce large amounts of colostrum (10 to 20 kg), but the concentration of immunoglobulins varies widely among cows. IgG concentrations are lower in first- and second-parity dams than in later parities, and the concentrations may be lower as the volume of colostrum increases. Calves from first-lactation cows have lower serum immunoglobulin concentrations than calves of older cows. Total immunoglobulin concentration tends to reach a maximum in the third or fourth lactation, almost doubling in amount compared with the first lactation (Devery-Pocius and Larson, 1983). The secretion of immunoglobulin ceases by the time of calving, and over 90% of immunoglobulins transferred at parturition can be expected to appear in the mammary secretion in the first four milkings.

Frozen Colostrum. If colostrum quality is measured and determined to be inferior, or if the cow does not have enough colostrum, then a source of high-quality colostrum is needed for the calf. This may not be a problem on large farms where other fresh high-quality colostrum is available, but on many farms, there may not be a fresh source. In these cases, having some high-quality frozen colostrum could solve this dilemma.

Freezing colostrum virtually eliminates nutrient loss during storage, providing an indefinite shelf life. Frozen colostrum is usually saved for newborn calves that need a colostral supplement because they did not receive enough or any colostrum. For this purpose, the colostrum from the first few milkings should be collected and frozen. The acceptability of thawed colostrum by calves is excellent. However, freezer facilities are required for this method of storage, and some extra handling of the colostrum is required to package it for freezing and to thaw it for feeding. Freezing colostrum in 1-L plastic bags, which can be frozen in a flattened form in a wafer measuring 18 cm^2 and 1.5- to 2.0-cm thick, facilitates more rapid thawing, in contrast to freezing and thawing in a bottle, which results in a much thicker mass to be thawed.

Two methods of thawing frozen colostrum before feeding to newborn calves have been compared. Thawing and warming colostrum to 104° F (40° C) in quart quantities in a pail containing boiling water required approximately 20 minutes, whereas the time required in a microwave oven was about 45 minutes. IgG_1 and IgG_2 concentrations in the sera of calves at 24 hours of age fed colostrum treated in boiling water were slightly lower than the respective immunoglobulin concentrations in calves fed colostrum treated in a microwave oven. Thus frozen colostrum thawed in a microwave oven provides a good source of immunoglobulins.

Colostral Supplements or Substitutes. Another option available to producers when high-quality colostrum is not available is the use of colostrum supplements. These supplements can be used as a means of increasing the quality of marginal colostrum, or they can be used when no other source of colostrum is available (Haines et al, 1990). These supplements alone do not replace high-quality colostrum. They do not contain sufficient quantities of immunoglobulins to raise the blood level in calves beyond what average quality colostrum can do. Commercially available colostral supplements are less efficient at providing immunoglobulin transfer and disease protection to newborn calves when fed at equal volume and similar immunoglobulin concentration (Garry et al, 1996). Similarly, the use of whey protein concentrate derived from ultrafiltrated and freeze-dried cheese whey, as a supplement to poor quality colostrum or as a replacement for colostrum, is unsatisfactory in preventing neonatal morbidity and

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mortality compared with a single feeding of pooled colostrum (Mee, et al, 1996). However, in emergency situations they do provide a viable option that is better than no colostrum feeding at all.

Parenteral Immunoglobulins. The administration of injectable immunoglobulins to calves that are hypogammaglobulinemic can increase the serum concentration of IgG but does not markedly influence incidence or severity of disease in young dairy calves (Quigley and Welborn, 1996).

Stored Colostrum as Feed for the Newborn Calf. The availability, storage, treatment, composition, and feeding value of surplus colostrum have been reviewed. Surplus colostrum may be considered a cost-free liquid feed for calves because it is unmarketable for human consumption. Sufficient excess colostrum should be available to feed heifer calves through 28 to 35 days of age. First-calf Holstein heifers and mature cows yield from 30 to 50 kg of colostrum from the first five postpartum milkings. With an average of about 44 kg of colostrum per cow and an average consumption of 11 kg per calf during the first 3 days of life, 33 kg of colostrum would be available per cow for feeding calves over 3 days of age. Calves commonly have been fed 1.8 to 3.2 kg of undiluted colostrum daily from day 4 of life to weaning. With an average daily consumption of 2.5 kg, colostrum from one cow can feed one calf through 16 days of age. If bull calves are sold within several days of birth, sufficient colostrum should be available to feed heifer calves to 4 weeks of age.

Stored colostrum is usually allowed to ferment and is fed as fermented colostrum. All the surplus colostrum collected from cows for the first six milkings after calving is stored. Dairy herds with 50 or more cows with calvings spread out over the year may benefit from feeding fermented colostrum. The major advantage is its low cost as a calf feed. When properly handled, fermented colostrum is an excellent feed, causing weight gains equal to those of calves fed whole milk or milk replacers.

Colostrum can be stored economically at ambient temperatures in plastic-lined containers with minimum handling requirements. The ideal temperature for fermenting colostrum is between 60° and 80° F (15.4° to 26.7° C). Under 60° F, fermentation is slow; over 80° F, fermentation is rapid and undesirable organisms can dominate the process. Plastic 20-gallon garbage cans make ideal colostrum containers. A disposable plastic bag lining the container makes cleanup easier.

The container is filled with colostrum as it becomes available over a period of several days. A tight lid should be provided to keep out flies and vermin. Daily stirring is not necessary, but the colostrum should be stirred before it is used so that the fat, curds, and whey are adequately mixed. Fermented colostrum should not be stored for more than 15 to 20 days, after which time the nutritional quality may be affected, the colostrum becomes malodorous, and calves are reluctant to consume it. Mold that might form on the surface of the colostrum should be skimmed off before use.

Losses resulting from spoilage and undesirable fermentation can limit the shelf life of stored colostrum. Warm temperatures may enhance putrefactive fermentation, which may be decreased by the use of chemical preservatives such as formic, acetic, and propionic acids and formaldehyde. Although chemical additives have not decreased the total number of microbes, some preservatives have decreased the numbers of coliform bacilli, molds, and yeasts while preserving a greater portion of the nutrient content of colostrum than is possible with natural fermentation. However, some unavoidable nutrient losses occur during storage at ambient temperatures, with and without chemical additives.

A given amount of colostrum can replace more than an equal weight of whole milk in calf feeding programs because of its high content of total solids. Dilution of colostrum diets with water is not necessary, but dilution may provide a more filling diet for calves fed once daily. Dilution with warm water may provide a more acceptable diet to the calf but does not increase calf performance. The amounts of colostrum fed and the rates of dilution should be designed to supply a desirable intake of solids to the calf. If the supply of colostrum is limited, a 2:1 dilution is effective. This can be changed to a 1:1 dilution with warm water as the calf becomes older. Colostrum with a total solid content of 18% can be diluted 2:1 with water to approximate the total solid content of whole milk at 12%. The diluted colostrum is then fed at a rate of 8% to 10% of body weight per day.

Increasing Specific Resistance of the Newborn Calf by Vaccination of Pregnant Dam

The passive immunization of calves against the infectious diarrheas caused by enterotoxigenic K99+ *E. coli*, rotavirus, and coronavirus by vaccination of the pregnant dam several weeks before parturition has received considerable research attention, and the results are promising. The pregnant cow is vaccinated at 6 and 3 weeks before parturition to stimulate the production of specific antibodies against the common enteropathogens; these antibodies are then transferred to the colostrum. The calf must ingest the colostrum and absorb the colostral immunoglobulins within 24 hours after birth for protection against systemic infection. The colostral immunoglobulins also provide local immunity in the intestine for the duration of their presence in the colostrum. This is known as lactogenic immunity, and it is contingent on the continued daily ingestion of colostrum or milk containing adequate levels of protective antibodies. The serum antibodies may provide protection against enteric infection if present in high titers and are transferred from the serum into the intestine. The knowledge that immunological dysfunction may occur in dairy cows from approximately 3 weeks precalving to 3 weeks postcalving may have practical implications for health management practices. In order to maximize the response to vaccination, it may be beneficial to vaccinate prepartum cows up to, but not past, 3 weeks precalving (Mallard et al, 1998).

Vaccination is an aid to good management and is not a replacement for inadequate management. The success of the vaccine is dependent on several factors. The pregnant cow must be vaccinated at the optimum time before parturition to ensure maximum production and transfer of antibodies in the colostrum. The concentration of antibody in the colostrum of vaccinated cows may vary widely, depending on the nutritional status and size of the cow, the amount of colostrum produced, the concentration of antigens in the vaccine, and the parity of the animal. The calf must still ingest colostrum in sufficient quantities soon enough after birth to acquire protection before invasion by pathogens. For the control of enterotoxigenic colibacillosis, the pregnant cow is vaccinated 2 to 6 weeks before parturition with either purified K99+ *E. coli* pili or a whole-cell preparation containing sufficient K99 antigen. Good protection is also possible when dams are vaccinated with a four-strain *E. coli* whole-cell bacterin containing sufficient K99+ pili antigen and the polysaccharide capsular K antigen.

The levels of K99+ *E. coli* antibodies in the colostrum of vaccinated cows are high for the first 2 days and then decline rapidly. These high levels of specific antibody protect the calf from enterotoxigenic colibacillosis during the first few days of life, which is the most susceptible period for the disease. Oil emulsion bacterins may elicit high amounts of antibody

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production after primary immunization, which may be sustained for up to 87 weeks after vaccination. Calves from these dams were protected from experimental challenge with ETEC.

Because mixed infections with rotavirus and coronavirus are common in diarrheic calves, the passive immunization of calves by vaccination of the pregnant cow with rotavirus and coronavirus vaccines has been examined (Saif and Smith, 1985). The colostrum of the majority of cows contains antibodies against rotavirus and coronavirus, but the levels decline rapidly in a few days to nonprotective levels in the milk at 3 to 5 days after parturition. These low levels in part explain the common occurrence of the disease in calves after 5 days of age. The colostral levels of rotavirus and coronavirus antibodies can be increased above naturally occurring levels by vaccination of the pregnant cow (Van Zaane et al, 1986).

The results of the field evaluation of the combined vaccines have been contradictory. The original rotavirus and coronavirus vaccines did not stimulate the production of antibodies that persisted at high enough levels in the milk of vaccinated cows compared with unvaccinated cows. The development and use of a combined, inactivated, adjuvant rotavirus and *E. coli* vaccine caused increased neutralizing antibodies in serum and colostral whey. The vaccine resulted in a decrease in the incidence of rotavirus shedding and of diarrhea in calves fed colostrum and milk from the vaccinated cows. Vaccines made from water-in-oil emulsions induce marked enhancement of rotavirus antibody titers in the serum, colostrum, and milk of vaccinated cows (Archambault et al, 1988).

An adjuvant vaccine containing inactivated rotavirus and coronavirus and K99+ *E. coli* significantly increased the serum rotavirus antibody level at the time of parturition by about six times in vaccinated cows compared with unvaccinated cows and increased the colostral whey antibody level by about 30 times in vaccinated cows compared with unvaccinated cows. However, by 7, 14, 21, and 28 days after parturition, the milk whey antibody levels had dropped by about 27-, 46-, 70-, and 93-fold, respectively (Sharpee et al, 1986).

Such sharp drops in colostral and milk antibody levels illustrate why vaccination for the viruses is not as effective as the *E. coli* vaccines. The colostral and milk viral antibody levels are not sufficiently high enough to provide protection when calves are most susceptible to rotavirus and coronavirus infections. One clinical field trial using an inactivated rotavirus vaccine combined with a K99+ *E. coli* antigen emulsified in oil adjuvant given intramuscularly to pregnant cows provided protection against diarrhea in calves under experimental and field conditions. However, in another field trial to evaluate the efficacy of a combined rotavirus-coronavirus and *E. coli* vaccine in Ontario dairy cattle herds, the vaccine was not effective in protecting individual calves from disease in general or diarrhea in particular, or in improving weight gain.

There may be several reasons for the poor performance of the vaccine. Continued feeding of immunoglobulin-rich colostrum for several days would be necessary to provide protection against rotavirus-associated diarrhea. Normally, dairy calves would not receive colostrum or milk from their dam for more than a few days compared with beef calves. This is why the daily feeding of stored colostrum from the first few milkings of unvaccinated or vaccinated cows can provide continued protection against the viral diarrheas. Also, the vaccine may not have been sufficiently antigenic to boost colostral antibody titers. Another explanation for the apparent ineffectiveness of the vaccine is that the vaccinated part of the herd protects the unvaccinated part or, conversely, that the unvaccinated part so badly contaminates the whole herd that the vaccinates are overwhelmed by the microbial challenge. There is also the possibility that producers who had vaccinated would expect their calves to remain healthy and hence might have ignored certain diarrheic calves or waited a few days longer than usual to treat a diarrheic calf. This could distort the comparison of the incidence of disease between vaccinated and unvaccinated calves.

One method of providing a daily source of viral antibody in the milk of calves for up to 2 to 3 weeks is to feed pooled, stored colostrum containing the antibody. Another method is to supplement the daily milk supply with colostrum containing high rotavirus antibody titers from vaccinated cows (Saif et al, 1983). Experimentally, a simultaneous intramuscular and intramammary vaccination of pregnant cows with a modified live adjuvant bovine rotavirus greatly enhanced colostral rotavirus antibody titers (Saif et al, 1983). This colostrum protects calves against experimental challenge with rotavirus when fed as a 1% supplement of the daily intake of milk. On a practical basis, feeding one-half colostrum from vaccinated or unvaccinated cows and one-half whole milk protects calves from rotavirus- and coronavirus-induced diarrhea from birth to 2 to 3 weeks of age, during which time they are most susceptible to these viral diarrheas.

Specific passive antibody immunity can be provided to newborn dairy calves against infectious bovine rhinotracheitis (IBR) by the vaccination of pregnant cows with the intranasal IBR vaccine, which is not abortigenic (Mechor et al, 1987). Vaccinated cows produce increased concentrations of specific antibody in the colostrum, which is transferred to the calves and protects them against the highly fatal form of systemic IBR. Vaccination of calves at 4, 6, and 12 weeks of age with an inactivated IBR vaccine may also provide protection (Straub and Mawhinney, 1988). Vaccination of pregnant cattle is also a successful method of controlling salmonellosis and may protect calves when they are most vulnerable to infection (Jones et al, 1988). A quadrivalent vaccine containing the killed antigens of BRSV, parainfluenza-3 virus, *Mycoplasma bovis*, and *M. dispar*, when given to housed calves at about 5 weeks of age, may provide some protection against respiratory disease associated with the above pathogens.

CALF NUTRITION FROM BIRTH TO WEANING

The major objectives during the period of birth to weaning are to control the incidence of dietary and infectious diarrheas, to obtain satisfactory growth rates, and to wean the calf successfully at about 2 months of age. Heifer replacements are expensive; therefore all available economical resources should be used to raise the heifer calves in a dairy herd, and they should be given high priority.

Digestive System of Newborn Calf

Certain parts of the intestinal tract of the young calf and its respective digestive enzyme activities have particular nutritional significance. These are reviewed briefly as background to understand the digestive disturbances of young calves that are nutritional in origin.

Abomasum

In the newborn calf, the abomasum makes up about 70% of the total stomach volume, in contrast with the adult ruminant, in which it makes up only about 8%. In the preruminant calf, liquid food flows through the closed esophageal groove directly into the abomasum, thus bypassing the

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forestomachs. The abomasum of the newborn calf is capable physically and biochemically of initiating the digestion of milk. It can undergo considerable expansion and hold large quantities of liquid. It secretes rennin, the milk-coagulating enzyme that clots the milk, yielding a casein clot and whey. The whey enters the duodenum within 5 minutes of feeding, and the casein clot remains in the abomasum. Rennin is also a proteolytic enzyme and is probably responsible for the breakdown of the milk clot in the early life of the calf before it develops any appreciable pepsin-hydrochloric acid proteolytic enzyme activity. The casein clot is degraded gradually by the enzyme action of rennin and/or pepsin and hydrochloric acid, and the partially digested proteins and fat are released at a fairly continuous rate over 24 hours. The main passage into the small intestines as well as further enzyme action by trypsin, chymotrypsin, and carboxypeptidases present in the pancreatic juice and by other peptidases secreted in the small intestine are followed by absorption from the small intestine as amino acids.

A gradual changeover from rennin to pepsin secretion in the abomasum occurs as the calf grows older. Rennin activity reaches a peak at a pH of 4, whereas the optimum pH for pepsin activity is about 2. Pepsin activity is low until the calf is about 3 weeks of age, at which time it begins to digest nonmilk proteins efficiently. Before the calf can digest nonmilk proteins (plant proteins, meat meal, and fish by-products), the abomasal juice must attain a pH of 2 and pepsin activity must be adequate.

Digestive Physiology of the Colostrum Fed Calf

Ideally, the neonatal calf should be fed colostrum from birth through the third or fourth day of life. Within the first 24 hours of life, the calf requires an abundant supply of immunoglobulins that must be readily absorbed into its bloodstream to establish immune competence. The syneresis of the abomasal clot allows the immunoglobulins in the whey to pass to the small intestine for immediate absorption before digestion by pancreatic enzymes while retaining casein and fat in the abomasum (Roy, 1990; Cruywagen et al, 1990). Adequate digestion of alternative liquids feeds, such as milk replacers, after the third or fourth day of life do not depend on this clotting action.

The preruminant calf is dependent solely on its own digestive enzymes in the absence of rumen bacteria and protozoa for the breakdown and assimilation of nutrients. Pregastric esterase and pancreatic lipase are added to liquid feedstuffs during the swallowing process through saliva and are important for the hydrolysis and digestion of the milk fat within the casein. All enzyme activity in the intestine is high at birth and dramatically increases between birth and 2 days of age because of the rise in mucosa protein content. Isomaltose, maltose, and sucrose are not present during preruminant stage. Lactose is the only known carbohydrate that the preruminant calf can digest before 1 month of age (Roy, 1990). The calf can use colostrum and postcolostral milk containing high levels of lactose because of the relatively high quantity of intestinal lactase that is produced shortly after birth. Calves less than 1 month of age are virtually unable to use starch, maltose, sucrose, or dextrin because of the lack of the digestive enzymes required to break these sugars down to their respective monomeric forms postruminally. When these undigestible sugars are added to milk replacers as an energy source before 1 month of age, diarrhea and other health problems often occur. The activity of intestinal lactase decreases at the time of weaning, along with increases of enzyme activity responsible for the digestion of more complex carbohydrates. This gradual turnover of enzyme activity allows the calf to digest and use the other carbohydrates added to milk replacers with less instances of diarrhea.

Curd formation occurs because chymosin (rennin) binds much of the casein and fat in milk and milk replacers within 10 minutes of feeding into a slowly digested curd. This curd is slowly digested over a period of 24 hours and its digesta empties from the abomasum. Abomasal enzyme action is maximal at 2 days of age and decreases during the first month, whereas pancreatic enzyme activity is minimal at 2 days and increases during the first two weeks. Peptic activity does not seem to vary with age (Toullec et al, 1992).

Following coagulation, the abomasal clot is degraded by proteolytic enzymes. Lactose and whey are expelled from the abomasum because of the contracting clot—a synergistic effect—and released into the duodenum where they are digested rapidly. The duodenal receptors modulate stomach emptying of digesta through the actions on the contractile processes of antral smooth muscle. When gastric emptying nears completion, the hydrogen ion mass appears to activate the release of somatostatin, which may be associated with the inhibition of gastric motility. Somatostatin does not seem to respond to the nonionic substances including butterfat and sucrose. Therefore the alteration in the physical or chemical nature of a milk-substitute diet may influence the nutrient delivery from the abomasum to the small intestine.

Most abomasal enzymes are in low concentrations in young calves but increase within the first 3 weeks of age. At approximately 3 weeks of age, the calf's digestive enzyme production diversifies and changes the digestibility and use of carbohydrates and protein sources dramatically. Therefore it is important that a neonatal calf milk replacer be formulated for proper digestion and use by the underdeveloped digestive system of the young calf that is less than 3 weeks of age.

Abomasal Clotting and Calf Performance

Clotting of milk in the abomasum of the calf has long been accepted as an important component of the milk digestion process in preruminant calves. Abomasal curd formation, consisting primarily of casein protein and milk fat, appears to be advantageous to the milk fed calf because of its function in slowing the release of digesta out of the abomasum and into the small intestine (Toullec et al, 1992). The clot slows down the passage of crude protein, dry matter, and fat (Cruywagen et al, 1990). Consequently, a gradual and more complete digestion and absorption of the nutrients consistently occurs between feedings. This is especially important for the newborn calf receiving colostrum; however, it has not been shown to have any effect on calves beyond 3 days of age (Heinrichs et al, 1994).

FEEDING THE DAIRY CALF FROM BIRTH TO WEANING

Details of the nutrient requirements of the preruminant calf in the first few weeks of life have been presented (National Research Council, 1989). The ingredients of major importance for satisfactory growth are energy, protein, and fat. The average digestible energy requirements in nursing calves has been reported to be 50 kcal/kg body weight per day for maintenance and 3 kcal/g body weight gain per day for growth (Medina et al, 1983). A 40-kg calf gaining 500 g per day requires 3500 kcal of digestible energy daily. The gross energy density of cow's whole milk is approximately 0.73 kcal/ml, and, with a digestibility of the nutrients in whole milk at 95%, the digestible energy content should be about 0.69 kcal/ml (Hand et al, 1985). A variety of liquid feeds including whole milk, waste milk, and milk replacers can be fed to calves that can provide all the nutrient requirements of the calf from birth to

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weaning and produces acceptable growth rates when fed in adequate amounts along with supplemental grains.

There are marked variations in the estimated protein and energy requirements of calves, particularly in the ruminant stage. These requirements are influenced by rate of gain, body size, age, diet, and other factors. A number of studies have shown that milk replacers, on an air-dried basis, should contain at least 20% crude protein, assuming good-quality protein. The optimum crude protein level for calf starters usually is considered to be about 18%. Other components of the diet and the rate of gain desired have a major effect on the amount of protein needed in feeds of the young calf. As the rate of growth increases, the optimum ratio of protein to energy increases markedly.

On the basis of data derived from four studies, the average requirements (and range) of the 50-kg, nonruminating calf for digestible energy are 47 kcal/kg (range, 41 to 52) body weight for maintenance and 3.3 kcal/g (range, 2.7 to 3.8) body weight for gain. The requirements for the ruminating calf weighing 50 to 100 kg are slightly higher for both digestible energy and protein.

Whole Milk

Following the 3-day colostral feeding period, dairy calves may be fed whole milk, a milk replacer, or a combination of these, depending on preference, availability, and economic considerations.

Whole milk is excellent for use in feeding calves, especially those that are being raised as heifer replacements. Whole milk is usually fed in two divided feedings at a total daily rate of 8% to 10% of body weight, depending on the size of the calf. Small-breed calves are usually given the smaller amount. Calves raised in hutches during cold weather should be fed at least 10% daily (Schingoethe et al, 1986). Calves may be fed solely on whole milk until weaning at 35 to 56 days of age. A calf starter diet containing 16% to 20% protein should be made available in small quantities (100 g/day) beginning the second week of life. This should be increased every several days so that the calf is consuming about 450 g/day before weaning, in addition to small quantities of good-quality hay. Calves should not be weaned until they are consuming about 400 to 600 g of dry feed per day. When the amount of milk or milk replacer is fed over a shorter period (3 to 4 weeks), the calf must be encouraged to eat dry feed at an early age. Early weaning at 3 to 4 weeks is a low-cost feeding method that accelerates the transition of the calf from a preruminant to a ruminant. However, some calves do not adjust effectively and are unthrifty for up to several weeks. They may also develop a chronic dietary diarrhea.

In a dairy herd on a milk production quota system, overquota milk can be marketed by feeding it to calves, which gives some return for the milk fed. The daily amount of whole milk and the duration of milk feeding can be extended beyond the usual weaning period, causing increased calf weights and reduced cost of dry calf feed. The amount of milk that can be disposed of through calves can be varied by extending milk feeding for up to 6 months. Cost-benefit analyses have suggested the following: (1) calves can be productively fed milk long past early weaning if selling the milk is not economical; (2) the value of milk fed to calves that are sold at market exceeds the cost of feed grains necessary to maintain milk production; (3) the feeding value of milk as measured by relative feed-to-grain ratios is greater than for calf starter, hay, or fishmeal; and (4) to avoid growth setbacks, calves should have their daily milk allotment gradually decreased before weaning.

Calves can also be fed a combination of whole milk and reconstituted skim milk powder (Jenkins and Bona, 1987). As much as 75% of whole milk fed to calves up to weaning could be replaced by reconstituted skim milk powder (10% weight/weight) fortified with vitamins and minerals, without any reduction in calf performance.

Antibiotic-Contaminated Waste Milk

The use of milk discarded from cows with mastitis and containing antibiotics (hospital-pen milk) as a feed source for calves (rather than discarding it) appeals to many producers (Wray et al, 1990). The practice is common, and hospital-pen milk is probably the most economical feed for young dairy calves (Goodger et al, 1993). In some herds, colostrum is pooled with milk from treated cows. However, hospital-pen milk should not be fed to calves during the first day of life to prevent bacteria from permeating the intestine during the period of absorption of colostral immunoglobulins. Milk from antibiotic-treated cows cannot be sold but, along with other waste milk, such as colostrum, has the potential to make a valuable calf feed. However, milk from cows that have mastitis that has been treated with antibiotics might cause infectious disease in calves, promote the development of drug resistance of enteric bacteria, and lead to the presence of drug residues. When milk containing antibiotic residues is allowed to ferment naturally, a reduction of the antibiotic levels occurs through degradation. However, the voluntary intake of antibiotic-containing milk fed fresh or fermented may be reduced because of decreased palatability, which causes less than optimum growth rates (Wray et al, 1990). Mastitic milk should only be fed to individually housed calves that will not come into direct contact with other calves. Mastitis pathogens can be transferred by direct contact, such as calves sucking other calves. Waste milk that is known to come from a cow with coliform mastitis, Johne's disease, and enzootic bovine leukosis should not be used. The economics and health implications of feeding such waste milk rather than good-quality milk replacers or whole milk must be considered before deciding on this feedstuff.

In some dairy cattle areas, male dairy calves are sold between 1 and 7 days of age and moved directly to abattoirs with no more than 1 day of movement through sales channels. Some of these calves may have been fed hospital-pen milk containing antibiotics, which could cause drug residue violations (Carpenter et al, 1995). In the United States over a 4-year period, the nationwide violation rate in samples from calves examined in abattoirs averaged 2% (Carpenter et al, 1995). A case-control study of Washington dairy herds experiencing drug residue violations in market calves found significant associations between violation occurrence and the management of calving cows, colostrum volume and management, and the person responsible for calf care (Carpenter et al, 1995).

Surveys of the management factors that contribute to antibiotic residues in dairy calves indicate that producers are not fully aware of the factors that influence antibiotic residues in the herd (Goodger et al, 1993). Veterinarians must inform producers about the importance of monitoring and record keeping, of limiting exposure of calves to pathogenic bacteria in waste milk, and of ensuring that label instructions for the use of antibiotics in the herd are followed.

The microbial content of milk fed to calves may vary widely depending on various interacting factors such as the origin of the milk or milk substitutes, preparation and handling procedures, storage conditions, environmental conditions, cleaning equipment, and management strategies. Fluid milk used as feed for calves in commercial dairy herds can contain a mixed bacterial flora, including some potential pathogens (Selim and Cullor, 1997).

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Milk that contains any hospital milk (categorized as waste milk) may have more viable bacteria than other types of milk, indicating that calves fed waste milk are exposed to a higher bacterial load than calves fed milk replacer or other nonhospital milk. Milk replacer and bulk-tank milk are less likely to have a high viable bacterial flora. Waste milk samples may contain *Streptococcus* sp. *Enterobacteriaceae,* and *Staphylococcus* sp. *E. coli* was isolated most commonly. Waste milk that has not been treated effectively by pasteurization to reduce the bacterial load before use as calf feed should be used with caution because it may contain a high number of bacteria that may be pathogenic to cattle and humans.

Milk Replacers

Brief History of Milk Replacers

The first widely accepted and used milk replacers for dairy calves were developed in the 1950s and were composed primarily of dried skim milk, dried whey, dried buttermilk, and animal fat (Heinrichs, 1994, 1995). Dried skim milk was the principal ingredient because of its low cost. These early products were poorly used by calves and contained limited fat content (10% versus 30% in whole dry milk). In addition, these early milk replacers contained large amounts of skim milk that had been heated severely during the drying process. This caused severe diarrhea in neonatal calves because of denaturing of casein proteins. Because of this and other factors, calves performed poorly on these early products; thus milk replacers were not as popular as they are currently. Current data from the National Dairy Heifer Evaluation Project (Heinrichs et al, 1995) found that 53% of calves in the United States were fed medicated milk replacer, and 12% were fed nonmedicated replacers. Nearly 60% of U.S. dairy farms use milk replacers for some or all of the feeding program for neonatal calves (Heinrichs et al, 1995). Approximate savings of $15 to $25 per calf compared with feeding whole milk can be realized by feeding calf milk replacers in the United States (Fowler, 1998).

Throughout the 1980s, continued efforts by the industry to find alternate sources of protein yielded mixed results. The addition of soy flour caused severe allergic reactions, abnormalities of the small intestine, and poor performance in calves because of the presence of trypsin inhibiting enzymes and allergens. Fish proteins, meat solubles, and other nonmilk proteins including cottonseed, oat, pea, rapeseed, potato, soy and wheat flour, corn, alfalfa, field bean, bacterial sludge, and blood were found inadequate for use in milk replacer formulations. Although there has been some success in using fish protein in milk replacers, investigations reported in the literature have generally not yielded satisfactory results.

The issues and problems of technological processing methods of both milk and nonmilk proteins were addressed in experiments, and as a result the use of some alternative proteins began to improve and eliminate the nutritional diarrheas associated with feeding high heat-treated, low-fat products. Greater concentrations of fats in milk replacers have been shown to significantly reduce the incidence of diarrhea. Both homogenization and low-pressure dispersion of fats cause good calf gains, feed efficiency, and digestibility. This is accomplished at moderate levels of total fat (20%). At higher fat levels (40%), however, homogenization causes markedly reduced calf performance and lowered nutrient digestibilities.

The National Research Council (NRC) has recommended that milk replacers contain certain minimum levels of nutrients, as shown in Table 9-2. Many of these can be adjusted depending on several factors as described below.

TABLE 9-2

General Nutrient Content Recommendations for Dairy Calf Milk Replacers

INGREDIENT	PERCENT OF DRY MATTER
Crude protein	18-24
Fat	10-22
Calcium	0.7
Phosphorus	0.6
Potassium	0.8
Magnesium	0.07
Sodium	0.09
Chlorine	0.18
Sulfur	0.26
	CONCENTRATION (PPM)
Iron	90
Cobalt	0.09
Copper	9
Manganese	36
Zinc	36
Iodine	0.23
Selenium	0.27
	CONCENTRATION (IU/LB)
Vitamin A	25,000-35,000
Vitamin D	5000-7500
Vitamin E	50-125

Since digestibility and utilization of different proteins used in milk replacers vary greatly, these recommendations serve as minimum guidelines to be followed and modified as situations dictate. In early life, digestibility is generally limited but digestibility and utilization of milk are high in the young dairy calf. A good approximation for whole-milk digestibility in a young calf is 95%. The same applies to milk products used in milk replacers as long as the processing procedures are such that quality is maintained. In general, milk replacer ingredients that are from nonmilk sources are used less efficiently than milk products, especially in the calf that is less than 3 weeks of age. Both the source and processing method of milk replacer ingredients have marked effects on the value of the overall product. In addition, human grade milk products must be used rather than the less-expensive animal grade milk products. This is due to the protein denaturation that occurs in the animal grade products when they are dried down under higher heating methods.

Protein Concentration and Sources

Whereas studies show that the protein concentration of milk replacers for the calf should be 22% (dry matter [DM] basis), other studies have demonstrated that levels of 23% to 25% may improve growth rates. In interpreting these studies, it is important to understand that some of the studies using high levels of curd protein are using nonmilk protein sources for all or part of the total protein. These studies demonstrate the effects of a lesser-quality amino acid profile in the protein source used, than that found in milk and milk products (lysine, methionine, and histidine in nonfat dry milk (lysine 2.868, methionine 0.907, and histidine

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0.981), skim milk (lysine 0.270, methionine 0.086, and histidine 0.092), and dried whey (lysine 1.030, methionine 0.241, and histidine 0.237). Therefore, even if higher levels of nonmilk or noncasein proteins are included in the milk replacer, this does not ensure adequate protein for the calf that is less than 3 weeks of age. Skim milk and whey protein concentrate are nearly equal in protein level (34%), whereas dried whey is only 11% to 12% protein. Because of the vast differences in level of protein between the two milk based feedstuffs, dried whey can serve as an energy source to substitute for skim milk in replacer; however, it must be included with another protein source for the replacer to meet the animals nutritional requirements. The 22% protein recommendation is suggested for milk replacers comprised only of milk proteins based on high digestibility. Crude protein levels should be increased in replacers that contain nonmilk protein sources to counter the effect of their reduced digestibility.

Partly due to the high prices of milk by-products, many modern milk replacers are formulated using high-quality soy-based products (Heinrichs, 1995). Soy protein isolates, soy protein concentrates, and chemically treated soy flours are often used in certain lines of milk replacers and have acceptable results in the dairy calf with respect to growth and health of the animal, provided that the soybean has been processed properly, which includes altering the proteins to reduce or eliminate any allergic reactions. These soy protein products are quite high in protein with soy protein isolates at 96% protein, soy protein concentrate generally at 66% protein, and soy flour at 50%. It is interesting to note that whether a soy product or an all-milk origin products such as dried skim milk, whey protein concentrate, delactosed whey, and dried whey are used, the majority of the ingredients in some modern milk replacers are from milk-derived (primarily whey) products.

Milk replacers are often more convenient than the feeding of whole milk or waste milk and may be more appropriate for health reasons than other sources of liquid feeds. From a convenience perspective, calves are generally housed in different areas of the farm than the milking herd, thus making the movement of these products to the calf area of the farm difficult. Milk replacers are manufactured with a variety of ingredients and levels of nutrients to meet the needs of a variety of farmers. In addition, antibiotics, ionophores, and coccidiostats can be added to milk replacers, which allows for added convenience on farms where these are needed or desired.

The milk replacer industry's need to find alternative protein sources has led to a variety of replacers containing both plant and animal proteins (Fowler, 1992). These replacers exhibit little or no clot formation because of the absence of casein proteins normally found in cow's milk. This lack of clotting has precipitated numerous studies with results that support (Petit et al, 1987a,b) and oppose (Petit et al, 1988; Strudsholm, 1988; Petit et al, 1989; Cruywagen et al, 1990) the physiological need for curd formation in the young calf.

Current milk replacer studies indicate that although they lack casein proteins, some nonskim milk proteins, whey protein concentrate, and soybean derived products are acceptable for the young calf if they are processed properly (Babella et al, 1988; Mir et al, 1991). Early data found that the use of noncasein proteins was limited and often caused diarrhea, low growth rates, and poor performance (Akinyele and Harshberger, 1983). Factors other than the lack of clotting were found to be responsible for the poor performance when compared with milk-fed calves. Morphological abnormalities of the villi lining the small intestine caused insufficient absorption and digestion of nutrients followed by poor performance in calves fed replacers containing soy proteins (Seegraber and Morrill, 1986). Allergens and antitrypsin factors in soy proteins decreased the intraluminal concentrations of necessary pancreatic enzymes (Khorasani et al, 1989; Gardner et al, 1990). Improper or inadequate processing and reconstitution at high temperatures were also observed to alter the proteins (Mir et al, 1991). All of these factors apparently increased the incidence of diarrhea, causing lower digestibility, nutritional deficiencies, and reduced growth rates. These studies have encouraged the industry to formulate and evaluate milk replacers based on nutritional quality rather than their clotting ability, as defined by calf performance. A review of the importance and physiological role of curd formation in the abomasum of young calves is available (Longenbach and Heinrichs, 1998).

Calves receiving whey and nonmilk proteins such as soybean in milk replacers can perform comparably with those receiving skim milk proteins (Tomkins and Drackley, 1992; Tomkins and Sowinski, 1992). This evidence suggests that clotting is not needed during the entire milk-feeding period. Studies of whey proteins found satisfactory weight gains and feed utilization in the first 30 days of life (Babella et al, 1988; Lammers et al, 1996a). Up to 66% of the casein in milk replacer was replaced with whey protein in milk replacer without affecting calf performance (Babella et al, 1988).

Young calves fed milk replacers containing insufficiently processed soya products like steam-heated soya flour perform less well than calves fed skim milk powder. Predisposed individual calves also develop immune-mediated intestinal dysfunction, apparent by circulating anti-soya antibodies, and diarrhea and motility dysfunction (Lallès et al, 1995). Soy protein concentrate and full fat soy flour have been found to be more effective with older calves (greater than 3 weeks of age) compared with milk protein–based milk replacers. Data shows that calves 3 to 5 weeks of age fed a soybean protein milk replacer significantly retained more nitrogen per day than those calves up to 3 weeks of age (10.8 vs −1.24 g, respectively) (Akinyele and Harshbarger, 1983). Similar weight gains as for milk-fed calves were found for calves fed nonheated processed soybean milk replacers (extracted, fermented, and extruded) from 0 to 3 weeks of age. However, significantly more weight was gained by calves by the age of 30 and 180 days than those at 6 days of age (Mir et al, 1991).

Calves less than 3 weeks of age were found to be unable to digest soybean proteins because of lower levels of pancreatic and proteolytic activity in the intestine. These gastrointestinal problems occurred because of the immune response stimulated by the presence of larger quantities of undigested protein in the intestines. Calves chronically fed antigenic soya become sensitized and develop intestinal motility dysfunction, causing chronic diarrhea (Lallès et al, 1995, 1998).

Waste milk from cows infected with mastitis or treated with antibiotics supported similar weight gains and incidences of calfhood diarrhea as compared with whole milk. Feeding colostrum as compared with feeding a casein-based milk replacer showed a significant difference in average daily gain of 0.719 vs 0.493 kg/day for the period of 9 to 30 days of age (Broucek et al, 1989). However, from 30 days to 120 days of age, insignificant but higher weight gains were observed for the colostrum-fed calves. Minimal health problems occurred between the two treatments. In an earlier study calves fed colostrum from 0 to 3 weeks of age gained at a rate of 0.56 kg/day (Muller et al, 1973). These results were not statistically different, but the dramatic decline in growth response from 29% to 9% after the third week of age could have been due to the larger percentage of casein in the colostrum as compared with whole milk (5.2% vs 2.6% of

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the total proteins) (Bondi, 1987). The incidence of diarrhea in colostrum-fed calves was likely higher because of higher fat and mineral content (Muller et al, 1973).

Dilution Rates of Milk Replacers

Milk replacer powders are usually mixed with water at dilution rates that result in a product that is 12% to 15% dry matter and fed at a fluid intake of 8% to 10% of body weight per day (Hand et al, 1985). Higher or lower dry matter concentrations have sometimes been associated with diarrhea, but the cause-and-effect relationship has not been documented.

Acidified Milk Replacers

The concept of feeding acidified milk replacer for ad libitum intake has attracted the interest of dairy producers (Nocek and Braund, 1986). Organic acids such as citric and propionic acids have been used to reduce the pH of the liquid substitute to about 5.2, which acts to preserve the solution, regulate intake, and foster the ingestion of smaller and more frequent meals throughout the day. Calves offered acidified milk replacer free choice digest the ingredients with efficiencies equal to those of calves consuming conventional milk replacer. The pH of the abomasal contents and the feces is lowered, which may favor normal physiological function and decrease the incidence of diarrhea (Woodford et al, 1987). Superior weight gains of calves fed acidified milk replacer for ad libitum intake have been documented (Nocek and Braund, 1986). The increased weight gains are especially significant in calves less than 3 weeks of age. Total dry matter intake from the milk replacer is increased and significantly less from grain than calves fed a comparable quality of milk replacer (Nocek and Braund, 1986). Compared with normal milk replacer offered either warm (38° C [100° F]) or at ambient temperature (3° to 14° C [37° to 57° F]) acidified milk replacer increases calf weight gain (Fallon and Harte, 1988).

The reconstituted milk replacer can be stored for up to 3 days, increasing convenience and saving labor. With such cold-acidified milk replacer feeding systems, calves can be housed in groups with ad libitum access to the milk replacer. Calves housed in group pens consumed more milk replacer and were heavier than calves housed in individual pens to 5 weeks of age (Richard et al, 1988). However, the economics of ad libitum feeding of milk replacer must be considered. Calves fed ad libitum consume more replacer, which leads to a higher milk replacer cost. They also consume more total liquid and urinate more, leading to increased bedding costs. Labor costs in group housing situations should be reduced, but careful observation of individual calves is still necessary to ensure adequate milk intake and to assess the health status of each calf on a daily basis. The cost-benefit ratio of such feeding systems remains to be established (Hand et al, 1985).

WEANING CALVES

Calves should be weaned only when they are capable of thriving on a nonmilk diet. They should be eating at least 450 g of dry feed daily—primarily a high-protein calf starter and some good-quality hay. They should be ruminants before being weaned. Limited whole milk or milk replacer feeding systems with early weaning at 3 to 4 weeks of age may be successful under excellent management conditions. However, under most practical conditions, it is uneconomical to wean heifer replacement calves too early. They may not adjust to the dry feed quickly and effectively and may become unthrifty for several weeks.

The trend toward early weaning, rapid growth, and early breeding stresses the importance of good calf starter rations. Calf starters should be fresh daily and palatable, with the grains cracked or rolled, and a nutrient composition of 20% protein, 70% total digestible nutrients (TDNs), and added vitamins and minerals. At weaning time, the calf should be consuming approximately 0.5 to 0.7 kg/day of calf starter, which increases rapidly after weaning when offered free choice. The amount can be limited to 2 kg/calf/day and can be fed along with good-quality hay and free-choice water until the calf is 6 months of age. Feeding dairy calves 3.8 L of milk once daily, weaning at 28 days, feeding a calf starter from birth to 56 days, and feeding a total mixed diet from day 57 through day 180 allows calves to attain a body weight that exceeds acceptable reported means at 6 months of age (Hopkins, 1997).

Development of Rumen Function

At birth there are no microflora in the rumen of the calf. The rumen becomes inoculated with microflora from the environment, including the hair coat, feces, and saliva of other animals; bedding; and feeds consumed. The types of microflora that proliferate in the rumen are those that digest and use the feeds eaten. In addition to feed substrates, the microflora require water to proliferate and digest feedstuffs in the rumen. When the calf eats dry feed, the abomasal groove does not function, and therefore the feed directly enters the reticulum and rumen where it must be digested or chewed further through rumination or cud chewing. Calves may begin to ruminate by 2 weeks of age, depending on the diet. If water is not provided to the calf in early life, then rumen microbial growth will be limited. Water that is consumed does not bypass the rumen through the esophageal groove but becomes available for the calf's rumen microflora.

The development of the rumen and reticulum of the calf is highly dependent on the diet. The rumen of the newborn calf is relatively small and thin walled and has little papilli development. Fermentation in the rumen is limited, and absorption cannot occur efficiently. If calves are maintained on milk diets for periods of 4, 6, or 8 weeks, the rumen will remain smaller in size and underdeveloped. In contrast, calves that receive grain beginning at 3 days of age will have larger rumens at corresponding periods of time, and their rumen function is much more developed at 4, 6, and 8 weeks of age than in calves on a milk diet. Furthermore, calves at similar corresponding ages fed milk and hay have limited rumen development. Their rumens are not developed nearly as much as those of calves fed grain and milk. Some calves on diets of a high level of high hay or other forages will have larger rumens, but the papilli development is limited. The rumen papilli allow for a marked increased area for absorption of nutrients and digestion end products. These provide the calf with a large amount of energy for the calf to grow.

The increased concentration of energy in grains causes the production of microbial end products of butyric and propionic acids, which is the major reason grain and not hay is recommended before weaning. The butyric acid produced from grain primarily stimulates the development of the rumen. Much of the butyric acid produced in the rumen by the bacteria is absorbed through the rumen walls as a normal part of rumen metabolism. Butyric acid provides energy for the growth and development of rumen size and function.

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A small amount of grain along with water promotes ruminal fermentation and the production of butyric acid, which allows the rumen to become more functional and better able to digest grain. The process is self generating and allows the early grain-fed calf to have significant rumen development at a young age, 3 to 4 weeks of age. Thus it is recommended to feed grain to stimulate rumen development, which allows weaning to occur at a much earlier age than traditionally done.

DEVELOPMENT AND DELIVERY OF CALF HEALTH MANAGEMENT PROGRAMS

Dairy cattle practitioners have been providing planned health management and production programs as a veterinary service for many years. The emphasis in those programs has been on the maintenance and improvement of reproductive performance, mastitis control, and consultation on feeds and feeding systems, all of which are designed to produce high-quality milk at the lowest cost commensurate with the resources available. For a variety of reasons, calf health and production were not given the priority they deserved, but veterinarians have now begun to develop and deliver calf health management programs.

Insufficient attention has been given to monitoring the performance of calves on dairy farms. Ideally, calves should be weighed at birth and weekly thereafter until weaning. Body weight gain is usually minimal during the first week of life, but gains of 300 to 500 g/day, depending on the breed of the calf, should occur after the second week of life and until weaning. Decreased growth rates are associated with decreased whole milk intake, inferior milk replacers, and subclinical diseases, such as chronic diarrhea and enzootic calf pneumonia.

The cost of raising dairy replacement heifers is a substantial portion of the overall costs of milk production, perhaps second only to the cost of feed. Many producers are unaware that this enterprise can account for 15% to 20% of total milk production costs, and a computerized spreadsheet program is available to estimate the cost of raising dairy replacements (Goodger et al, 1989). The program allows the producer to calculate the costs of raising calves to calving for the particular conditions in the dairy using current calf populations and current facilities in the herd. Dairy producers have underestimated calf mortality rates and tended to rank calf disease low in economic importance. The dairy replacement heifer is a key asset for increasing milk production and profits in a dairy herd (Donovan and Braun, 1987).

The production potential of heifers is a result of all previous breeding and management decisions. Many dairy farms follow approved calf and heifer health management practices, but several aspects of management need improvement (Heinrichs et al, 1987a). The most important of these include the care and feeding of the newborn calf and the types and amounts of feeds fed to young calves, both of which have been shown to be related to high calf mortality. The role of the veterinarian is to educate the producer to understand the principles of calf health and production management and to adopt approved practices that lead to healthy calves that can grow at acceptable rates and become economical heifer replacements.

Surveys of management practices on dairy farms have revealed a lack of systematic understanding of the factors that are vital in calf health management (Heinrichs et al, 1987a; Goodger and Theodore, 1986). In spite of the long-known importance of colostrum, a significant percentage of producers do not appreciate the important factors that influence the passive transfer of colostral immunoglobulins in calves and what is required to ensure a high level of colostral immunity in the calves. Colostrum intake is often left to the calf, and most producers are unsure of the amount of colostrum obtained by the calf. Some producers vaccinate pregnant cows to prevent infectious diarrhea of calves but do not make the effort necessary to ensure that the calves ingest or are force-fed a sufficient amount of colostrum early enough after birth. The veterinarian must adequately inform producers about the importance of the entire sequence of events necessary to take maximum advantage of dry cow vaccination.

In large dairy herds, labor-intensive practices such as supplemental feeding of colostrum, close and frequent observation of the calving area, prompt removal of calves from the potentially infectious environment of the calving area, and separation of first-milking colostrum may not be practiced because of the labor required (Goodger and Theodore, 1986). Surveys have shown that calf mortality is lowest when a family member cares for the newborn calf, but calves in some herds, especially large herds, are often raised by hired labor, who frequently have other duties and do not have the same concern for health of the calves as would a family member. In the first 24 hours, calves need relatively intensive care, and this may conflict with hired labor schedules and other duties. In areas with herds that average less than 100 cows per dairy, family members usually feed and care for the calves.

There are four major goals in dairy calf management: (1) enhance the calf's immune system as soon as possible, (2) reduce stress and exposure to infectious disease pathogens, (3) provide adequate nutrition to ensure that the calf can resist disease, and (4) provide adequate treatment of calves with disease. There is substantial information available on how to achieve these goals, but the management efforts of dairy producers appear to be inconsistent and haphazard. Calf management practices and health management decisions on large dairies can be scored with a list of questions, which covers all aspects of young calf production (Goodger and Theodore, 1986).

The delivery of an effective calf health and production management program requires the establishment of a simple record-keeping system that records all pertinent calf health and production data as well as analysis and interpretation of this data by the veterinarian, who works with the producer or those caring for the calves to ensure that they understand the well-known risk factors that make calves susceptible to disease. In large dairy herds, epidemiological approaches can be used to investigate neonatal calf mortality with the objective of measuring risk factors (Thurmond, 1986). Some guidelines for the veterinarian are:

1. Work with the calf management personnel. All management success is conditional on the active participation of the producer.
2. Work within the conditions of the particular farm.
3. Determine the baseline of health and production when the program begins so that progress can be measured later.
4. Begin with the basics, such as colostrum and colostral immunity.
5. Introduce changes gradually and monitor changes in health and production.

REARING CALVES ON PASTURE

In many countries where grass is plentiful for several or more months of the year, young calves can be reared successfully on grass beginning shortly before or after being weaned from milk or milk replacer. In New Zealand, and to a lesser extent in Britain, most calves born in the spring are routinely placed on pasture soon after birth. Successful

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rearing of dairy calves on pasture can also be achieved in North America. Calf performance on pasture, with few exceptions, has equalled or surpassed indoor rearing and has produced healthier, thriftier calves.

Several factors are important for the successful rearing of young calves on pasture. The quantity and quality of grass available are of primary importance because of the highly selective nature of grazing calves. Young calves can starve on unsuitable pastures unless they receive a supplemental concentrate. Digestibility trials have found that calves from 3 to 5 weeks of age can digest approximately 75% of herbage dry matter. Compared with indoor feeding of hay and concentrates, pasture rearing has led to calves ruminating at an earlier age and developing greater rumen size and capacity. Pasture quality can also alter the response of calves to concentrate feeding. Calves on excellent pasture alone can make greater weight gains than calves on poorer pasture with supplementary grain feeding. Under conditions of poor pasture, low levels of nutrition, and adverse weather conditions, young calves are highly susceptible to parasitic gastroenteritis, which causes severe unthriftiness.

Dairy calves can be turned out to grass at 3 or 4 months of age under a leader-follower rotational grazing system during the summer months and can gain 0.55 to 0.74 g/day while receiving a daily grazing supplement of about 1.8 kg of concentrate. The followers can be yearling cattle and sheep.

The major problems in rearing young calves on pasture include insufficient good-quality grass to support optimum growth, mineral deficiencies (particularly of the trace minerals), parasitic gastroenteritis, and lungworm pneumonia.

Assessment of the nutritive value of pasture for young calves is a practical problem. Spring-born calves that have received cow's whole milk or a good-quality milk replacer until weaning at 6 to 8 weeks of age perform well on lush spring pasture. The performance of the calves must be monitored regularly by visual observation or, preferably, by monthly weighings. When grass is not plentiful or not of good quality, calves should be maintained on milk replacer for longer periods and supplemented with concentrate while on pasture.

A salt-mineral mixture must be provided for young calves on pasture. The composition of the mineral mixture depends on the mineral content of the forages and soil in the area. There are seven major minerals, or macrominerals (calcium, phosphorus, potassium, sodium, chlorine, magnesium, and sulfur), and eight trace minerals, or microminerals (iron, iodine, zinc, copper, manganese, cobalt, molybdenum, and selenium). The minerals that are commonly deficient in cattle grazing on native, unsupplemented pastures are phosphorus, copper, and cobalt. Mineral deficiencies are particularly common in cattle of all ages grazing in the tropics. Lack of good-quality pasture and multiple mineral deficiencies are major factors in the poor growth rates and prolonged delayed onset of puberty in calves grazing in tropical countries. It is not uncommon for dairy heifers in such areas to have their first calf at 3 to 4 years of age.

The control of parasitic gastroenteritis in calves that are pastured during the grazing seasons in countries with a temperate climate is now possible. Strategic chemotherapy involving the use of anthelmintics at selected times combined with various systems of grazing management have been successful. In the Northern Hemisphere, in the so-called Weybridge "dose and move" system, young cattle are dosed with an anthelmintic in late spring before the infection pressure is high and then moved to a pasture ungrazed by cattle since the previous autumn. Grazing management systems used to control bovine ostertagiasis have included rotational grazing of cattle, alternate grazing of cattle with different host species, or integrated rotational grazing of different age groups of cattle. Improved weight gains have also been reported when susceptible dairy calves were rotationally grazed on permanent pastures and followed by replacement heifers. The success of this system, known as the leader-follower system, depends on the careful management of the paddocks grazed by the calves and on the assumption that 2- to 3-year-old dairy heifers are immune to infection by *Ostertagia ostertagi*. Thus the calves are only permitted to graze the upper leafy part of the herbage before being moved onto the next paddock, thus avoiding the mass of third-stage larvae thought to be concentrated in the lower quartile of the herbage and subsequently ingested by the incoming immune heifers. In the Southern Hemisphere, the same principles have been used for the control of ostertagiasis, and the reservation of safe pasture at times of the year when levels of infestation are known to be increasing has been the method widely advocated in areas such as Australasia.

VEAL CALF PRODUCTION

Veal is made from dairy bull calves, largely of the Holstein breed, which unlike heifers are essentially surplus products of the dairy industry. The raising of dairy calves for veal production is profitable when the economic conditions are right. A readily available supply of inexpensive healthy male calves, good-quality milk replacers at an economical price, reliable labor, inexpensive housing, and market potential provide the opportunity to produce veal calves. Before the commercial veal industry developed about 30 years ago, such calves were killed or sold for slaughter within days after birth as bob veal or were grown as grass-fed veal calves, which were raised on grass pasture, sometimes supplemented with grain, for a few months to a year.

Classes of Veal

Four classes of veal are now recognized in the United States: (1) bob veal calves, which are 1 to 3 weeks of age and weigh up to 68 kg, (2) special-fed veal calves, which are more than 3 weeks of age, weigh 68 to 182 kg, and are fed a liquid milk-based diet, (3) non-special-fed veal fed a variety of diets, which are also more than 3 weeks of age and weigh 68 to 182 kg but are fed a solid diet, and (4) calves of more than 182 kg and fed no special diet; also called heavy or western veal calves, which are raised similarly but weigh more than 182 kg (Wilson et al, 1995).

Bob veal is obtained from young dairy-type calves and is primarily used for processed meat. Non-special-fed calves are fed a variety of diets including milk replacer, grain, and forages (hay, silage, or pasture). They may be of different ages at processing, and several cattle types may be utilized. Special-fed veal calves (also referred to as formula fed, fancy, or nature veal) are fed a liquid milk replacer diet in which the iron content decreases through the last half of the production cycle. The calves are raised in confinement for 16 to 20 weeks of age and are marketed at live weights of 160 to 210 kg.

According to the USDA (1991) approximately 33% of the male dairy calves marketed are used for bob veal production, 40% for special-fed veal production, and the remainder for a variety of subsequent feeding systems, including beef production. However, up to 95% of the male dairy calves in some areas may be used in veal or beef feeding systems. The numbers of calves used for bob veal, special-fed veal production, and other calf production declined 71%, 22%, and 73%, respectively, in the United States between 1986 and 1991. However, because of increased market weights of special-fed veal calves, total tonnage of veal

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produced has remained fairly constant in the last few years (Wilson et al, 1995).

Neither bob veal nor grass-fed veal is considered a high-quality product. Bob veal has pale muscle meat, which is a desirable characteristic, but it tends to have a soft and even slimy consistency; grass-fed veal is generally pink or red and can be tough or grainy, depending on the age at which the calf is slaughtered (Schwartz, 1990). Formula-fed veal calves—also known as milk-fed, prime, nature, special-fed, or fancy veal—are sustained on a low-iron, milk-based liquid diet until they are slaughtered at up to 20 weeks of age. This is done to produce pale, tender muscle meat, called white veal, which fills several cultural markets and an upscale specialty market, such as in restaurants and gourmet food stores.

The formula-fed veal industry developed in Europe and the United States in part because of the surplus of milk. In the United States, it now has become a billion-dollar industry that uses over $200 million in dairy feed products annually. Annually, in the United States, 1.2 million dairy bull calves are raised as formula-fed veal, which represents about 40% of the total veal market.

Targets of Performance

Consumers of veal prefer a well-fleshed calf of a "blocky" conformation, with only a small cover of white fat. The meat must be pale pink, an index of youth to the packer that is found only in an anemic calf. The North American market desires a live weight ranging from about 200 to 300 lb (90 to 135 kg). The calves should grow at a rate of over 2 lb (0.9 kg) daily with a feed conversion of 1.4 to 1.5 kg of milk replacer powder per kilogram of body weight gain. At the end of the feeding period, calves often gain in excess of 3 lb per day. A 100-lb calf should be ready for market in 12 to 16 weeks.

A survey of white veal calves in commercial farms in Ontario found a mean average daily gain for shipped calves over the entire production period to be 1.1 kg/day. The overall percentage of calves receiving at least one individual treatment was 59%, with an average number of treatment days per calf of 3.3 (Sargeant et al, 1994a). The mortality rate was 3.7%, and 5.1% of the calves were culled. Pneumonia was the single largest cause of death. Peak death and culling losses occurred during the sixth and seventh weeks of production. Calves shipped to slaughter averaged 130 days in production with a range of 64 to 189 days. Mean weight at time of entry was 45 kg with a range of 26 to 90 kg. Overall mean weight of calves at the time of marketing was 194 kg with an individual calf range of 106 to 269 kg. The mean farm level market weights ranged from 173 to 198 kg (Sargeant et al, 1994b).

There is a growing interest in raising calves on grain diets to produce a carcass that is lighter in weight than traditional beef, while circumventing some of the real or perceived problems of white veal production. A survey of red veal calf production practices and indices in commercial red veal farms found mean entry weight of 119 kg, mean individual calf marketing weight of 291 kg, 116 mean days in production, and average daily gains of 1.52 kg over the entire production period (Sargeant et al, 1994a). The percentage of calves receiving one or more treatment days was 55%, with an average number of individual treatment days per treated calf of 3.9. The population mortality during production was 5.4%, with 0.8% of calves culled (Sargeant et al, 1994a).

Welfare Aspects of Veal Calves

Formula-fed veal calves are usually raised under what has been termed by critics as "factory farming" conditions, in which calves are kept and fed twice daily in small, individual stalls or crates, with a minimal amount of bedding and without exercise, from less than 1 week of age until they are slaughtered. An emerging problem in veal calf production is the politics and welfare of the animals (Schwartz, 1990). Concerns have been expressed about confining calves in crates, feeding them liquid diets only, and limiting their iron intake to produce pale meat. Veal calves may be housed in individual raised floor stalls with no bedding, a restricted floor space for lying down, and no special contact with adjacent calves. These restrictions may encourage calves to reach each other at feeding times or to attempt to turn around in their stall to see each other. When veal calves are reared in groups, they may suck each other's navels and penises. If straw is provided in group pens, they eat the straw, which may exaggerate the incidence of abomasal ulcers. When they are housed in groups of 15 to 50, automatic milk replacer dispensers can be installed economically at the rate of one per 15 animals, which may overcome the sucking problem. It appears that a well-designed individual stall with a slatted front for visibility and a sufficiently wide floor that allows the calf to stretch out is satisfactory and humane. The Ministry of Agriculture, Fisheries, and Food of Britain (1985) has stated, "The use of veal crates or boxes is not an acceptable system and cannot be condoned."

Animal rights activists have focused on the conditions used to raise veal calves. An excellent publication on the politics of formula-fed veal calf production is available (Schwartz, 1990). Activists believe that such conditions are inhumane, alleging that they lead to anemia, behavioral deprivation, and more infectious disease and chemical residues, presumably because the calves are treated more often than calves raised under conventional conditions. There is evidence that the campaign of the activists has had a negative impact on the sales of veal. This is compatible with the results of a national survey, which found that the veal industry is perceived negatively by the meat-consuming public compared with the beef industry, which is still perceived positively. A congressional bill has been introduced that would make it unlawful to (1) keep a calf in an enclosure in which the smallest dimension is less than the length of the calf, measured from the tip of its nose to its tail, plus 6 inches; (2) prevent the calf from having an appropriate amount of physical contact with other calves; and (3) give the calf feed that does not meet standards to be established by the Secretary of Agriculture. It would also be unlawful to transport, sell, or purchase a calf that was known to have been kept or fed in violation of the act, and to fail or refuse to allow the secretary or any representative of the secretary to make inspections (Schwartz, 1990). The major issues are as follows:

1. Should calves be raised individually or in groups, and, if they are raised individually, should housing in small enclosures be stopped?
2. Is the raising of marginally anemic (low-normal hemoglobin/packed cell volume) calves inhumane?
3. Do residues of antibiotics, sulfonamides, and other chemical feed additives in veal need better control?
4. Should the federal government regulate the veal industry, mandate an industry-based method of regulation, or leave the industry to it own devices?

The above issues are being debated. However, before animal husbandry legislative changes are put into effect, it would seem prudent to perform the necessary research to obtain information to deal with these issues. New legislation intended to improve the health and well-being of veal calves should be based on sound science.

A recommended code of practice for the care and handling of specially fed veal calves is now available in Canada

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(Agriculture Canada, 1988) and was coordinated by the Canadian Federation of Humane Societies. It deals with housing, feed and water, delivery and postnatal care of veal calves, growing, attendants, supervision and protection of calves, transportation, processors, emergency procedures, space requirements, and wind chill factors. Other veal calf guides are also available.

The effects of different rearing systems on the development of calf behavior, health, cleanliness, and injuries have been examined (Webster et al. 1985a,b). Suckler cows with their calves at pasture, early-weaned calves bucket-fed in individual pens, early-weaned calves teat-fed and group-reared, veal calves bucket-fed in individual crates, and veal calves teat-fed and group-reared were compared. The major behavioral abnormalities of veal calves in individual crates were as follows:

1. Discomfort while standing on slats in the first few weeks of life. This could be improved by the use of wood shavings or similar bedding in the crates for the first few weeks after arrival and by ensuring that the gap between slats does not exceed 2 cm (Webster et al, 1985a).
2. The inability to adopt a comfortable sleeping posture above the age of about 10 weeks. This could be improved by prohibiting the use of crates less than 85 cm wide for calves weighing over 100 kg.
3. Veal calves deprived of access to solid food showed a much higher incidence of purposeless oral behavior than other groups. This did not reduce the time they spent resting relative to other calves, however, and the abnormal behavior did not last long enough to be described as an obsession.
4. Veal calves in individual crates were not alarmed abnormally by the presence of humans as long as they were exposed to the normal sights and sounds of farm activity.

The welfare of veal calves in commercial facilities has been examined using a multidisciplinary approach (Stull and McDonough, 1994). The low mortality rate, rapid growth rate, and absence of stress indicators demonstrate the ability of commercial agricultural systems to effectively manage and care for immunologically deficient calves. An important management advantage is the opportunity to individually feed and monitor a calf. The use of stalls in a controlled environment assists in the individual management of veal calves. Neither the constraints of individual stalls nor the diet of veal calves, which is formulated to decrease the iron content after 8 weeks of age in an effort to reduce the red color of the meat, are considered to have a deleterious effect on the calves. The total time spent lying down or the number of transitions from recumbency to standing are not different between calves housed in individual stalls and group-penned calves. The marginal clinical hemoglobin levels does not affect the growth or health status of the calf from 12 to 16 weeks of production. Veal calves with marginal anemia do not become anorexic, which is a clinical finding associated with anemia. The major factor that adversely affects the welfare of veal calves is an inadequate level of serum colostral immunoglobulins. This can be minimized by the ingestion of sufficient quantities of high quality colostrum in the first 24 hours after birth, preferably the first 12 hours.

The effects of the different systems of rearing on health, cleanliness, and injury revealed that veal calves in crates tended to be caked with feces around the legs and hindquarters, which they were unable to groom from about 8 weeks of age (Webster et al, 1985b). Veal calves in straw yards were generally dirtier overall than any other group. In general, calves were free from external injuries, but 20% of the veal calves in crates had abrasions and bruised or swollen knees. The system of rearing veal calves in groups in straw yards with ad libitum access to milk from an automatic dispenser appeared to present a greater risk for disease and mortality than housing veal calves in individual crates and bucket feeding controlled amounts of milk twice daily (Webster et al, 1985b). These results, along with the behavioral observations described above and the fact that production costs are higher when veal calves are fed ad libitum, indicate that free-choice feeding of veal calves in groups is not yet a satisfactory alternative to rearing veal calves in individual crates (Webster et al, 1985a).

Because they consume large quantities of fluids, formula-fed veal calves produce large quantities of urine. Therefore the building must be well drained and ventilated to remove the excess moisture. It is estimated that each calf will produce 1 to 2 gallons of manure and urine per day. Three gallons of wastewater are generated per calf per day in feed preparation and cleaning. Facilities should be planned with a total of 5 gallons of waste generated per calf per day.

Concern has also been expressed about the humaneness of producing veal calves that are marginally anemic. Quality veal is traditionally pale ("white") in color because the calves are fed an all-liquid, milk-based diet that is low in iron. The pallor of the meat is largely the result of low concentrations of myoglobin and other iron-containing compounds in muscle (Welchman et al, 1988). Formula-fed calves are not allowed to consume roughage, which would provide a source of iron and stimulate normal rumen development, rumen microbial production, and vitamin B_{12} synthesis (Schwartz, 1990).

Whether the low iron intake and marginal anemia affect the health and vigor of the veal calves is uncertain. The goal of veal calf producers is to deplete myoglobin but not to decrease the blood hemoglobin to below 8 g/dl, the low end of the normal range for cattle. The published literature on the possible effects of marginal anemia is not consistent and is open to discussion. There is no good evidence that feeding veal calves liquid diets low in iron that leads to low-normal or marginally anemic hemoglobin concentrations can cause increased susceptibility to disease or impaired productivity (Schwartz, 1990). Normal appetite and growth have been maintained in veal calves at hemoglobin concentrations greater than 7 g/dl and with a concentration of iron in the milk replacer of 25 to 30 mg/kg DM. The borderline of iron deficiency anemia at 16 to 20 weeks of age is defined as a hemoglobin concentration of 5 g/dl and a saturation of total iron binding capacity of 10% (Welchman et al, 1988). The addition of extra iron in a normal commercial milk replacer given from the end of week 6 until the end of week 16 of the fattening period influenced feed conversion positively, without a loss in meat quality (Wensing et al, 1986). The mortality, blood, and growth performance indexes measured in veal calf units suggest a generally acceptable level of well-being of special-fed veal calves housed in individual stalls (Wilson et al, 1994).

Health Management of Veal Calves

The major causes of economic loss resulting from disease in veal calf operations are the infectious disease enteritides and pneumonias. The enteritides are commonly associated with the low serum and intestinal levels of immunoglobulins in calves that are purchased from different, usually unknown, sources. Immunocompetence of the calves for veal production is a concern of the dairy and veal industries for both economic and animal welfare reasons. Calves have low levels of circulating IgG at birth, and consumption of

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colostrum by the calf within 24 hours after parturition provides passive immunity and reduces subsequent mortality. The percent of calves receiving adequate amounts of high-quality colostrum and thereby developing satisfactory passive immunity varies regionally. In a Pennsylvania study Wilson et al (1994) concluded that between 60% and 80% of calves entering veal production systems had received colostrum. Adequate immunity will enhance the health and well-being of the calf throughout the feeding cycle, thereby necessitating less use of antimicrobials and providing increased financial stability for veal farmers. In California, the leading milk-producing state in the United States, colostrum is collected at the dairies and sold to facilities specializing in raising dairy heifer calves.

Longitudinal surveys of veal calves have revealed that the usual enteric pathogens are present in calves within a few weeks after their arrival (De Visser et al, 1987). Veal calf hemorrhagic enteritis is a fatal syndrome of major concern to the veal calf industry (Mahdi-Saeed et al, 1993). Infection with *E. coli* strains that produce enterotoxins and cytotoxins may be causative agents. Calf pneumonia may also be associated with low levels of protective immunoglobulins, but inadequate ventilation of the calf barn probably has a greater influence on the health of veal calves raised under intensive conditions. Outbreaks of respiratory disease have occurred in veal units that used a high-pressure sprayer for the weekly cleaning of occupied calf rooms.

Bob veal is a class of veal defined as 1- to 3-week-old calves weighing up to 68 kg. Bob veal calves are predominantly bull dairy calves shipped to slaughter within a few days after birth. High rates of postmortem condemnation because of icterus have existed for a number of years in bob veal calves that appear normal at antemortem inspection. Icterus condemnations comprise a substantial proportion (41%) of total condemnations of bob veal (Gray et al, 1995). Normal and icteric bob veal calves have significant increases in total bilirubin concentration, and icterus bob veal calves is secondary to unconjugated hyperbilirubinemia. Lack of colostrum consumption is strongly associated with icterus in bob veal calves. Bob veal calves that had not consumed colostrum had significantly higher total bilirubin and creatine kinase levels (Gray et al, 1995).

Yellow discoloration in veal calves slaughtered at 26 weeks of age has been associated with chronic hepatitis of unknown etiology (Groot and Gruys, 1993).

Purchase of Calves

Ideally, all calves should weigh at least 45 kg (100 lb) and be at least 10 days old when delivered to the vealing unit. If possible, they should be purchased directly from dairy farms rather than from auction marts. This ensures obtaining calves of optimal physiological maturity and with adequate levels of serum immunoglobulins. In other words, a 100-lb calf that has survived for 10 days has a better chance of living for a few months than a smaller calf that is only a few days of age. In the absence of an economic and practical laboratory method of identifying calves that are a good risk, the probability is greater that the larger calf at 10 days of age possesses a greater degree of inherent or acquired resistance to infectious disease than the smaller calf at 2 days of age. An algorithm can be used to assist in deciding how to manage purchased calves with low serum levels of immunoglobulins and to determine what premium can be paid for calves with high immunoglobulin levels.

Within a few hours after arrival, all calves should be given a complete physical examination by the veterinarian. Calves with obvious abnormalities, such as navel infection, arthritis, diarrhea, or pneumonia should be isolated, treated if deemed necessary, or culled immediately. Each calf should be weighed on arrival and identified with a tag, and an individual calf card should be made out and clipped to its pen. All relevant information for that calf is recorded in chronological order: weight in and out, date in and out, diagnosis of illness, treatments, feed refusals, and nature and date of vaccination given. These cards are then analyzed when the calves are shipped to market.

The vealing unit should be filled with calves within the shortest time possible, and almost all calves should be marketed as soon as possible. This all-in, all-out system is essential for the control of infectious diseases. After the calves are marketed, the facilities are cleaned out, disinfected, and allowed to dry and remain vacant for several days or a few weeks before being restocked. The system of introducing new calves and selling a few on a continuous basis does not allow for effective disease control.

Feeding

Veal calves are usually fed solely on a reconstituted liquid milk replacer containing 16% to 24% fat (DM). The digestive problems associated with these milk replacers occur during the first few days, when the calves are adjusting to the ration, and later in the feeding period, when large amounts of the liquid are ingested at each feeding.

Nutritional diarrhea occurs in calves that consume too much milk replacer during the first few days. This can be controlled by feeding only 50% of the total daily allowance to new calves on the first day, increasing up to 75% on the second day, and finally giving a full allowance on the third to fifth day. The total daily allowance is increased each week as the calf grows older. The nutritional diarrhea associated with the feeding of milk replacers containing heat-denatured skim milk has been described (see "Milk Replacers" section). There is some evidence of an allergic hypersensitivity to milk replacers fed to veal calves (Flederus et al, 1988). Affected calves exhibit diarrhea and hyperemia of the conjunctivae and nose.

Abomasal bloat occurs during the finishing period in veal calves, which are by this time consuming large quantities (9 to 12 kg) of liquid milk replacer per feeding. The disease is highly fatal. Affected calves become bloated and die within 15 minutes after first being noticed. The cause and pathogenesis of the disease are unknown, but presumably it is related to the ingestion of large quantities of milk replacer, most of which enters directly into the abomasum. This sudden overloading of the abomasum may cause a reflex outpouring of fluids from the abomasal mucosa, which may further exaggerate the dilatation. Death results from peracute abdominal distention and acute heart failure caused by failure of venous return.

The method of feeding—once or twice daily, the temperature of the milk replacer when fed, and the use of buckets, nipple pails, or automatic dispensers—may affect the performance of the calves under certain management conditions. In general, however, almost any feeding system is successful if properly used with good care, management, and sanitation.

Feeding veal calves in groups with automatic milk replacer dispensers has some advantages over bucket feeding. The need for sucking is satisfied thus reducing the incidence of cross-sucking, including preputial sucking and urine drinking. Bucket-fed calves in group housing must be tied up during the first 6 to 8 weeks of the feeding period to control these problems. With automated feeding, the calves do not have to be tied up and the milk replacer can be provided more than twice daily, which saves labor (Maatje et al, 1993). However, the growth rate and feed intakes of calves fed automatically are lower than those of calves in individ-

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ual crates. In addition, sick calves fed automatically were not detected easily based on behavioral changes of reduced feed intake alone.

Some problems occur in veal calves that appear to be associated with feeding in the finishing system (Breukink et al, 1988). The failure of the esophageal groove reflex in some calves causes ruminal drinking. A large amount of milk is deposited in the rumen instead of the abomasum, causing fermentation of the milk in the rumen. This may be explained by the observations that affected calves seem to gulp their milk rather than suck it from the pail. Affected calves are chronically bloated with ventral abdominal distention, loss of appetite, unthriftiness, and loss of weight, and they have a long, dry hair coat. The feces are sticky and clay like. Large volumes of foul- or acid-smelling, grayish-white fluid can be siphoned off the rumen. Most calves become ill 2 to 3 weeks after the start of the finishing period, beginning with occasional feed refusal and chronic bloat. Extensive villous atrophy along the small intestine is characteristic. The pathogenesis is not well understood, but some calves may not maintain their reticular groove reflex into the fattening period. The experimental administration of milk into the rumen of calves has caused a similar syndrome (Van Weeren-Keverling Buisman et al, 1990). Ruminal drinking can be cured by the use of a rubber nipple floating on the surface of the milk, and it can be prevented by training calves to suck, using the attendant's fingers or a nipple, rather than gulp milk.

Lesions of the abomasum of veal calves are common. Approximately 60% to 75% of the abomasums of veal calves have lesions at slaughter (Wiepkema et al, 1987). The lesions consist of superficial erosions restricted to the mucosal layer, ulcers that may penetrate into the submucosa, and scars (the star-shaped remnants of ulcers). The lesions are predominantly in the pylorus. The possible relationship between stress or stereotypical behavior in veal calves and abomasal injury and disease has been examined. Biting and licking did not show a relationship, but tongue playing did (Wiepkema et al, 1987). Providing calves with roughage leads to a decrease of abnormal behavior, such as chewing the pen and tongue playing, and a reduction in hairballs. However, roughage enhances the occurrence of ulcers. The incidence and severity are greatest when calves are fed milk replacers ad libitum with access to roughage (Welchman, 1987). There is no evidence that the lesions affect the growth rate of calves. They are difficult to detect on clinical examination but are not considered to be significant on a welfare basis. The pathogenesis is uncertain, but local ischemia followed by focal necrosis or the stereotypic behavior and stress of veal calves in confinement may be factors (Breukink et al, 1989). The use of a beta-agonist such as clenbuterol has been examined as a prophylactic measure, but there are insufficient data to support a recommendation for its use.

Vaccination

Because veal calves commonly originate from many different sources, their immunological background also varies considerably and it is difficult to plan an effective, reliable immunization program. The control of acute undifferentiated diarrhea in veal calves depends on the purchase of healthy calves that have an adequate colostral status and on the minimization of the natural challenge by the calf's environment.

The use of modified live virus vaccines for the control of IBR and enzootic pneumonia caused by parainfluenza-3 virus infection may be considered in veal calves. Most veal calves are marketed by 16 weeks of age, and the use of viral vaccines at an early age, soon after the calves have arrived in the unit, is controversial. Colostral immunity begins to wane at 4 to 6 weeks of age, and vaccination with viral vaccines may be considered shortly after this time.

Housing

Veal calves are usually raised under intensified conditions in which many calves are housed in individual pens with raised floors.

The majority of North American veal farms use individual stalls or pens. Canadian and U.S. guidelines (Agriculture Canada, 1988; AVA, 1994) recommend stalls with a minimum width of 66 cm and length of 168 cm for calves weighing up to 202 kg. Most renovated individual stalls are 66 to 76 cm wide, with length of 168 cm; these dimensions are the current industry recommendations (AVA, 1994). Floors are constructed of either wood slats or plastic-coated expanded metal; fronts and sides are of wood slats. The stall sides between calves are usually 61 cm in length. The back of the stall is usually open; calves are tethered to the front of the stall with fiber or metal tethers 61 to 91 cm in length.

The use of individual stalls and the practice of tethering calves has been criticized because of limited social interaction between calves, lack of total body self-grooming, and restricted movement (Schwartz, 1990). The tethered calf can stand or lie in a natural, sternal position and take several steps either forward or backward (Albright et al, 1991; Stull and McMartin, 1992). Calves can reach and groom most parts of their bodies. Proponents of individual stall systems contend it allows regulation of air temperature and humidity through heating and ventilation, effective managing and handling of waste materials, limited cross contamination of pathogens between calves, individual observation and feeding, and, if necessary, examination and medical treatment with less stress from handling.

For lighting in veal calf housing facilities, American Veal Association (AVA, 1994) recommends that adequate levels of light be available for inspection while feeding or monitoring. In a recent study of 10 commercial veal facilities, all barns were equipped with adequate supplemental lighting; 6 of the 10 facilities had natural light sources through windows or doors, and none of the facilities incorporated darkness as a deliberate component of the production system (Stull and McMartin, 1992).

Because veal calves are fed large quantities of fluid, they give off large quantities of moisture in their urine and feces, and an effective ventilation system is necessary to remove excess moisture. Supplemental heat may be necessary during cold winter months to maintain a satisfactory minimum inside temperature of at least 50° F (10° C). In cold climates, the calf barn must be insulated with material having an R value of 15 in the walls and 20 to 25 in the ceiling. Continuous air exchange through the building at a minimum rate of four changes per hour is essential. In cold climates, for the winter months, the most satisfactory method is to bring in fresh air over the heating unit. During the summer months, 30 air exchanges per hour are desirable. Minimum ventilation requirements are to have 5 to 10 cu ft/min/100 lb body weight for winter and 50 cu ft/min/100 lb body weight for warm weather. With any system, careful management and common sense in operation are essential to its success, regardless of its design. Veterinarians should consult their local state or provincial agricultural engineering extension service for assistance in evaluating the ventilation system of calf barns. When in-

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vestigating a problem with respiratory tract disease in a group of housed calves, the ventilation system and its adequacy assume primary importance. Floor pen area should be 20 to 25 sq ft/calf. Ventilation systems for veal calf environments are currently being evaluated and correlated with calf health, behavior, growth, and carcass traits (Wheeler et al, 1997).

The flooring types used in special-fed Holstein veal calves have been compared for their effects on average daily gain, body weight, blood parameter, or carcass weight or grade. There were no differences between groups of calves kept on oak wood slats, rectangular vinyl-coated slats, and diamond-shaped, vinyl-coated slats (Wilson et al, 1998).

Surveillance System

Each calf should be examined twice daily for clinical evidence of disease. A nasal discharge, crusty nose, salivation, dyspnea, coughing, diarrhea, reluctance to get up, and refusal to feed are common clinical findings in sick veal calves. The diagnosis and treatment given should be recorded on the individual calf card; a summary of diseases and mortality should be prepared, analyzed, and interpreted; and the necessary control procedures instituted on a regular basis.

A decrease in appetite is one of the first and most reliable indicators of anemia in veal calves. A concentration of 25 to 30 mg of soluble iron/kg dietary dry matter provides sufficient hemoglobin for normal appetite, growth, and oxygen transport as well as provides carcasses light enough in color for the veal trade.

Because veal calves are slaughtered for meat, there is the potential for antimicrobial and other drug residues in calves that were treated for infectious disease or that received waste milk containing antimicrobials. Antimicrobial residues can be found in the urine of calves that consumed milk from mastitic cows that were treated with antibiotics. The live animal swab test is advocated for use on commercial dairy farms as a screening test for detecting antibiotic residues in the urine of calves and cull dairy cows. The swab test on premises (STOP) is used in the abattoir to test for the presence of residues in kidney and muscle.

Health Management of Replacement Dairy Heifers

The success of raising replacement heifers is of major importance to the viability and profitability of a dairy herd. An average of 25% to 35% of the cows in a dairy herd is culled annually. In addition, 10% to 12% of dairy calves born die within the first 2 years of life (NAHMS, 1992). This section describes health management programs for heifers from the time of weaning until calving and entry into first lactation. The alignment of this program with the producer's objectives for raising replacement heifers is essential. The principal components of a program for replacement heifers involve attention to nutrition, housing, reproductive performance, disease control, and genetic selection. The effect of a replacement heifer program is determined by the degree to which it completes the health management cycle. The use of record keeping and monitoring systems allows the continual assessment of heifer performance and provides the direction for changes in management. The resulting new levels of performance can be evaluated against industry standards or farm-level targets. After accounting for the effects of external factors, the continuous monitoring effort can lead to further management planning. The continuation of this cycle promotes improved health and performance (Fetrow et al, 1987).

OBJECTIVES OF RAISING DAIRY HERD REPLACEMENTS

Unlike many other food animal industries, dairy herds have tended to maintain systems to rear their own replacement animals. In some situations, economic conditions favor purchasing replacements from an outside source or contracting a third party to raise the farm's heifers. In the development of a system to raise replacement heifers, a dairy producer has five major objectives to achieve.

Maintenance or Expansion of Herd Size

The replacement program should provide an abundant, readily available supply of animals to replace cows culled from the milking herd. In addition, there should be a surplus of heifers available for sale or to allow for a progressive increase in lactating herd size.

Age at calving and herd turnover or culling rates of cows are two of the largest factors affecting herd replacement numbers that must be raised to maintain herd numbers (Table 9-3). Additional heifers on the farm would then be available to sell or improve the herd genetically.

Calving by 22 to 24 Months of Age

Calving and entry into first lactation by 22 to 24 months of age minimizes the total nonproductive days and maximizes lifetime profitability.

Sufficient Growth for Minimal Dystocia at First Calving

In order to be prepared for calving at the desired age, replacement heifers need to be large enough to calve without an increased rate of dystocia. This objective involves nutritional management to promote an optimum growth rate.

Maintenance of Health

The prevention of clinical and subclinical disease is a major factor in the ability of replacement heifers to meet the objective of 22 to 24 months of age at first calving. Survivability and lifetime productivity are also affected by the state of health during the replacement-raising period.

Genetic Progress

An important objective of the dairy herd replacement process is to produce replacement heifers with genetic merit superior to that of the current lactating herd. This genetic improvement may be expressed by increased productivity, improved efficiency of production, or enhanced resistance to disease. Genetic progress is dependent on the availability of sires of known genetic merit through artificial insemination (AI) and on the use of predictive indexes of the genetic potential of the replacement heifers.

COMPONENTS OF HEIFER HEALTH MANAGEMENT PROGRAMS

A successful health management program must be designed to assist the dairy producer to meet the objectives of raising replacement heifers. The program involves attention to five major health management disciplines (Box 9-1).

Each of these disciplines should be organized and performed to achieve completion of the health management cycle (Fig. 9-2). A prerequisite for effective incorporation of each of these disciplines into a replacement heifer health management pro-

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TABLE 9-3

Heifer Herd Size for a 100-Cow Dairy Herd and a 10% Heifer Cull Rate

Percent Cow Turnover Annually (Culling Rate)	Age at First Calving (mo)				
	22	24	26	28	30
26	53	58	63	67	72
30	61	76	72	78	83
34	69	76	82	88	94
38	77	84	92	99	106
42	86	93	101	109	117

From Heinrichs AJ, Swartz LA: *Penn State Ext Circ* 385:18-32, 1989.

BOX 9-1

Components of Heifer Health Management Programs

Nutritional management
Housing
Reproductive performance
Health and disease management
Genetic selection and numbers of replacements

gram is the implementation of a record keeping and monitoring system that allows the calculation of indexes of performance. With this monitoring system the current status of the replacement program can be assessed. The results of the assessment allow important management decisions to be made and a plan of action to be formulated and implemented. As monitoring of the replacement herd continues, the record of performance under the new management plan allows determination of the outcome of the program. It is important to account for the external factors and conditions that may have affected the outcome. Previously established goals and target values should be used to assess the performance outcome. In addition, the level of performance should be compared with standard values generated by monitoring a larger population of herds. These standard values may be available from regional dairy record processing centers or may need to be generated on a local basis from a number of herds participating in a replacement heifer health management program.

Each replacement heifer management discipline is presented here using this program format. The major indexes of performance, as well as currently suggested targets or performance standards, are described. An example of the use of this feedback cycle in the process of conducting a health management program for replacement heifers is given in Fig. 9-3.

Nutritional Management for Replacement Heifers

Completion of the anatomical and physiological changes that occur up to and at the time of weaning is a prerequisite for successful nutritional management of growing heifers. The majority of calves on an adequate feeding program, up to weaning, are ready to change from a milk or milk product-based diet to a dry feed ration at 8 weeks of age. The details of the preweaning feeding program have been described earlier in this chapter. In some management systems or with some individual heifers, the recommended age at weaning has to be altered.

Nutrient Intake and Feeding Programs

When the dairy calf is properly weaned at 4 or more weeks of age, the wall of the rumen, including the thickness of the wall and its papilli, is moderately well developed but not yet equivalent to that of a fully functioning adult ruminant. The diet of weaned calf should be formulated to maximize rumen development, which includes the rumen wall thickness and an increased number and surface area of the rumen papilli. The surface area of the rumen becomes more highly vascularized to allow for increased absorption of nutrients, including volatile fatty acids that are major end products of rumen bacteria. It has been estimated that the surface area of the rumen increases from less than 1 square foot in a newborn calf to a very large surface area in the adult ruminant. This transition occurs in a relatively short time, requiring a large amount of energy and protein for tissue growth. Complete rumen development usually requires 4 to 6 months and is heavily dependent on diet and feeding management. The higher the level of fermentable energy intake of these animals, the more rapid the rate of rumen development (Beharka et al, 1996). Thus calves fed high-level grain diets have more rapid rumen development than those fed high-level forage diets. In addition, high-quality, more digestible feeds and forages that contain more energy and more rapidly degradable energy for the rumen encourage faster rumen development. Propionic and especially butyric acids promote rumen development (Nocek et al, 1980).

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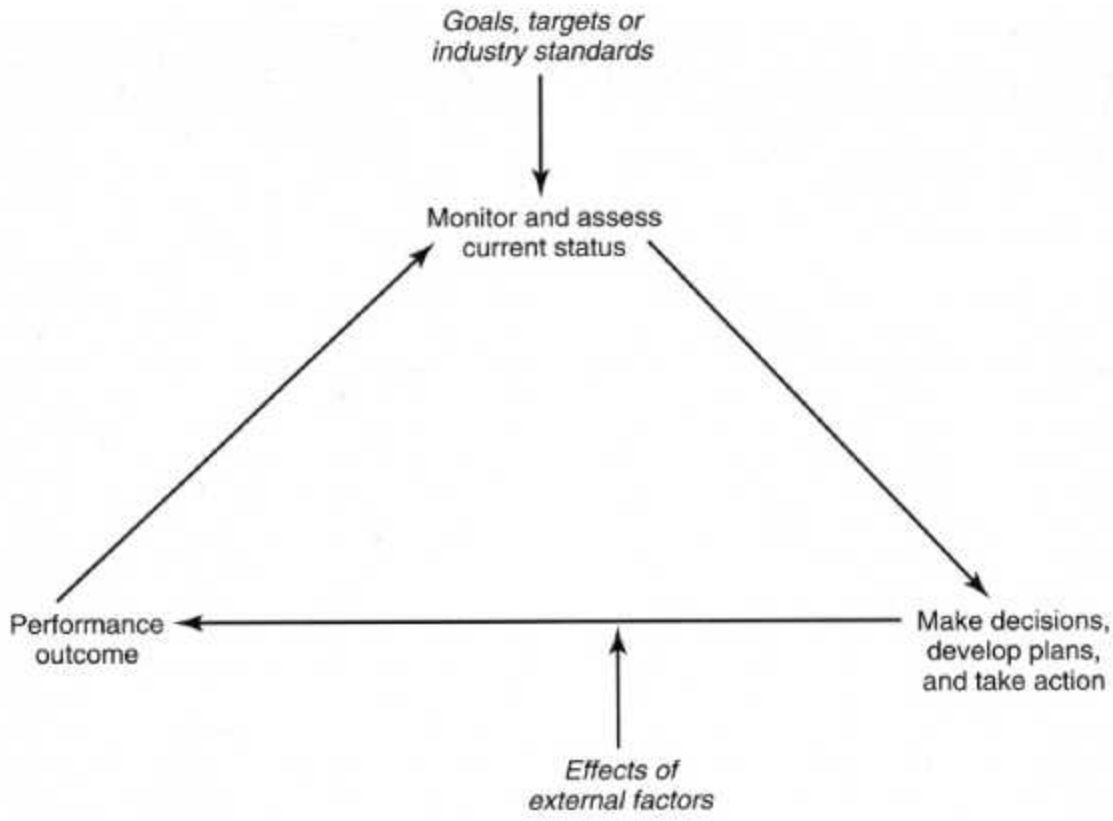

FIG. 9-2 Health management feedback cycle.

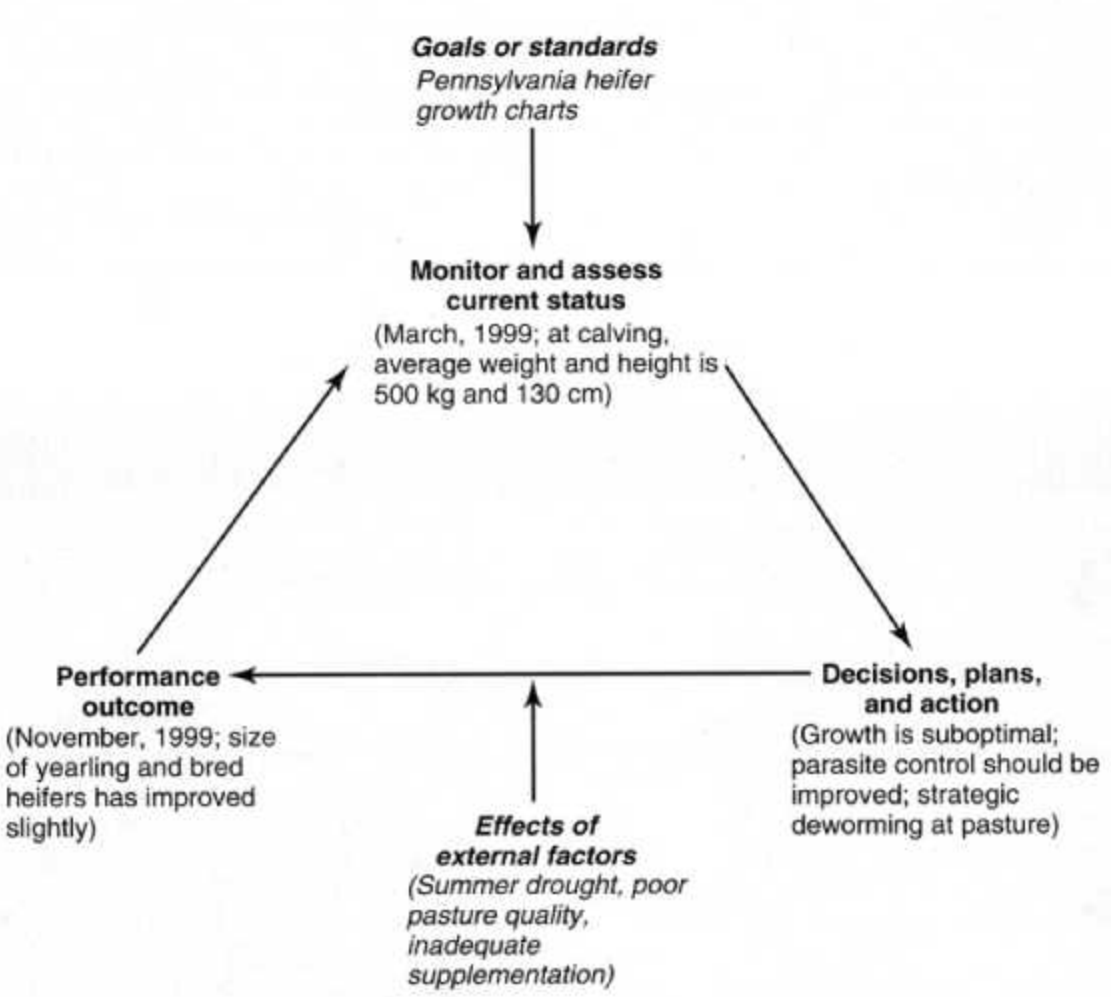

FIG. 9-3 Health management cycle in action. The current size of replacement heifers at calving is compared with industry standards. Growth is determined to be less than the desired rate. Parasite control is one option for improved performance, and a strategic deworming program is implemented. New levels of performance 7 months later show slight improvement. However, seasonal nutrition may have been a limiting factor. Continued monitoring can lead to new plans and actions.

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At weaning the liquid feed portion of the diet should be reduced and supplemented with a good free-choice grain mixture along with free-choice water. For heifers up to 6 months old, free-choice grain is recommended to a maximum rate of 5 to 6 lb/head/day. Young heifers consume much less forage than grain on a dry-matter basis. As the animals mature and grow larger, forages can make up a greater part of their diet.

The recommendations for nutrient intake and feeding program in the 2- to 6-month age range have undergone marked revision (National Research Council, 1989). Postweaning heifers up to 6 months of age are too young to depend on forages for the majority of their nutrient requirements. A 2- to 3-month-old heifer requires 75% of the nutrients from grain sources and 25% from forage. From 3 to 6 months, a diet with a 50:50 ratio of forage to grain provides the correct nutrient balance. In most feeding programs, grain is fed to support the appropriate dry matter intake; forage is fed free choice. For example, from 2 to 6 months of age, a heifer would be fed 1.4 to 1.8 kg of grain/day. With the provision of good-quality forage on a free-choice basis, this heifer gradually increases the forage:grain ratio of her total dry matter intake by increasing forage consumption. At 2 months of age, a heifer eating 1.6 kg of grain consumes only 0.6 kg of additional feed (forage), whereas a heifer at 6 months of age eats 4.5 kg of forage, or about 33% of the total feed consumed. Table 9-4 summarizes recommendations for suggested dry matter intake and forage:grain ratios for each age group of replacement heifer.

For the postweaning age group, the success of the nutritional program depends on two factors. First, adequate bunk space should be provided so that each calf has freedom of access to both grain and roughage without aggressive competition. This degree of access can be accomplished by housing replacement heifers in small groups (6 to 10) of relatively equal age and size in a facility with bunk space for each animal. The second important factor involves providing the opportunity for the change in amounts of forage consumed, as previously described. Forage quality should be monitored carefully for calves aged 2 to 6 months. Fine-stemmed, mold-free hay is preferred. Stemmy, moldy, or other poor-quality hay with lower digestibility, reduces forage intake and retards growth. If digestion of forage relies heavily on the young heifer to remasticate the material successive times in order to reduce the material to a particle size small enough to move through rumen undigested, dry matter intake will be reduced. The young calf is not as efficient as the adult cow at mastication.

A high-quality cool season grass, legume, or legume-grass hay from a second or third cutting should be fed. Such forages are normally lower in fiber, have greater leaf:stem ratios, and are normally more digestible than other feedstuffs on the farm. Forages that are less stemmy and fed dry are more palatable to young animals than forages that are coarse and stemmy. Fermented feeds such as haylage and corn silage can be fed to calves 4 to 6 months of age, provided that they also are high quality.

Fermented forages are most palatable when fresh. In the case of fermented feeds, normally within 8 to 12 hours (especially in the summertime) these feeds start to heat and become moldy. This is a process of refermenting by the yeast and molds found naturally on these feeds, which is a normal evolution of fermented feeds. Along with the growth of yeast and molds, heating of the forage causes the production of a variety of unfavorable end products, including ammonia and other nitrogenous compounds. Many of these are volatile and create a feed that is foul smelling and not as palatable for the calf, thus reducing intake. Mold growth will be very prevalent after 12 hours and will greatly reduce palatability. Thus, if silage is fed to calves, it must be replaced each day and preferably twice daily during warm summer months. This often does not happen on many farms because of time and labor constraints, and thus the recommendation is often made not to feed fermented forages to young calves. In reality, the nutrient content and digestibility are the primary factors that should dictate which forage is fed, yet the feeding management on a farm can alter these recommendations. The quality of forages fed to these young animals will determine how much protein and other nutrients are needed in the grain mixture. The types of forages commonly fed to heifers up to 6 months are shown in Table 9-5. Grain mixtures for heifers may be as simple as

TABLE 9-4

Recommended Dry Matter Intake and Forage: Grain Ratios for Adequate Growth Rates in Dairy Replacement Holstein Heifers

Age (mo)	Body Weight (kg)	Total Dry Matter intake (kg/day)	Forage:Grain Ratio	Crude Protein of Grain Ration (%)	Total Digestable Nutrients (%)
2	75	1.8-2.3	25:75	15	70-75
3	100	2.7-3.2	50:50	14	66-68
6	180	4.5-5.0	67:33		
9	250	6.3-7.3	75:25		
12	325	7.3-8.2	75:25	12	65
15	400	8.2-9.0	100:0		
18	475	9.0-10.0	100:0	12	62-65
21	550	8.2-10.0	100:0		
24*	620	8.2-10.0	80:20	12	62-65

*Expected calving at 24 months of age.

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corn, soybean meal, vitamins, and minerals, or may be as complex as desired. Sample grain mixtures for young heifers fed the example forages from Table 9-5 are shown in Table 9-6. In geographical areas where less palatable and less digestible warm season native grasses are grown, the grasses should not be fed in appreciable amounts to young calves if maximum growth rates are to be achieved.

From 6 months to breeding age, nutritional management principles similar to those for younger heifers should be applied. The housing system should allow for small groups of heifers (10 to 15) in order to achieve appropriate control of the feed and for adequate observation. Timid heifers, and those not reaching expected growth performance, should be separated for special attention. A 6-month-old heifer consuming 4.5 to 5.0 kg of dry matter per day and fed 1.3 to 1.8 kg of grain with free-choice forage is at a forage:grain ratio of 67:33. By 12 months of age, a heifer being fed 1.8 kg of grain consumes 7.3 to 8.2 kg of total dry matter for a forage:grain ratio of 75:25 (Table 9-4).

Information about the forage quality and nutrient content is essential in making these feeding recommendations. The forage quality affects the protein available from roughage sources. In turn, this determines the protein content required in the grain mix and the quantity of grain to be fed. A mixture of good-quality grass and legume hay, or a combination of legume hay with limited corn silage, creates a balanced ration with the previously suggested amounts of a 12% protein grain mix. However, a mixture of corn silage and grass hay has less protein content. In this case, the ration should be supplemented with a 16% to 18% protein grain mix. If the forage component of the ration were entirely good-quality legume hay, a grain mix of lower protein content (8% to 10%) would be adequate. Examples of the amounts of grain needed with varying levels of forage quality are given in Table 9-7.

Total mixed rations can be fed to growing heifers, but requires careful attention to providing the appropriate forage:grain ratios for each age group. This would require sev-

TABLE 9-5

Sample Forages for Dairy Heifers Younger than 6 Months

	Dry Matter Basis (%)			
	Mixed Mainly Legume Hay	**Mixed Mainly Grass Hay**	**Corn Silage**	**Mixed Mainly Legume/Haylage**
Crude protein	22.0	16.0	8.8	19.9
Available protein	—	—	—	19.1
Acid detergent fiber	30.7	36.0	28.9	38.0
Total digestible nutrients	70.0	63.0	67.8	60.0
Calcium	1.3	0.7	0.25	1.11
Phosphorus	0.29	0.25	0.23	0.31
Magnesium	0.22	0.18	0.17	0.23

TABLE 9-6

Sample Grain Mixtures for Dairy Heifers Younger than 6 Months According to Forages Being Fed

	Mixed Mainly Legume Hay	**Mixed Mainly Grass Hay**	**75% Mixed Mainly Grass Hay and 25% Corn Silage***	**75% Mixed Mainly Grass Hay and 25% Mixed Mainly Legume Silage***
	Grain mixture, as fed basis†			
Crude protein(%)	16.0	18.0	18.0	16.0
Acid detergent fiber (%)	7.7	8.2	8.3	8.1
Calcium (%)	0.19	0.48	0.53	0.43
Phosphorus (%)	0.4	0.42	0.42	0.41
Magnesium (%)	0.19	0.21	0.21	0.21
Grain level (lb/head/day)	36287	36285	36285	36285

*Refers to proportion of mixed, mainly grass hay to corn silage and mixed, mainly legume silage on a dry matter basis.
†Grain mixtures can contain shelled corn, oats, soybean meal, minerals, and vitamins. All minerals and vitamins should be balanced at a minimum, accsording to National Research Council. Ionophores should be added to the mineral mixtures.

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TABLE 9-7

*Quantity of Grain Required to Balance a Replacement Heifer Ration with Varying Degrees of Forage Quality**

Age of Heifer (mo)	Levels of Forage Quality (kg)			
	Excellent	Good	Fair	Poor†
2-6	1.3-1.8	1.8-2.0	2.0-2.7	—
6-9	0.9	1.8	2.7	2.7
9-12	0-0.5	1.3	1.8	3.6
12-18	–	0.9	1.3	3.6
18–Calving 2‡	–	0-0.9	1.3	3.6
Calving 2‡	0.9-1.8	1.3-2.7	2.7-3.6	4.5

*Large amounts of calcium (15% to 25%) and phosphorus (10% to 20%), trace mineral salt, and frost-free water should be available at all times.
†Deficiencies of poor roughage cannot be corrected completely by grain feeding. Young heifers should receive good roughage or grains high in fiber for proper rumen development and function.
‡Two months before calving.

eral rations for the various age ranges, which only large dairy herds would have the economy of scale to implement.

After the heifers have been bred (14 to 15 months of age), good-quality forage provides an adequately balanced ration with no addition of grain. A complete ration consisting of half legume hay or hay silage and half corn silage is nutritionally adequate in protein and energy. However, a ration based on hay or hay silage of only average quality requires the addition of 0.9 to 1.4 kg/day of grain to provide the energy requirements. A ration consisting totally of corn silage is too high in energy and relatively low in protein and would cause suboptimum growth and excess fat.

As bred heifers approach calving, additional nutrients may be required to maintain body condition for their first lactation as well as for their growth and that of the fetus. A forage:grain ratio of 80:20 would be appropriate, depending on forage quality. Grain intake should be increased gradually to reach a level of 0.5% of body weight at calving. For example, a heifer weighing 570 kg would benefit from a gradual increase in grain intake to the level of 2.8 kg/day at calving.

The emphasis in nutritional management of replacement heifers is on balancing the ration for protein and energy requirements. However, the recommended levels for minerals, vitamins, and fresh water have been documented (National Research Council, 1989). Care must be taken to ensure that deficiencies in these nutrients do not exist.

Because replacement heifer rations are easy to formulate, the inclusion of low-cost feed additives as a means of supplementing lower quality forages may provide a great cost-benefit advantage over traditional grain sources (Rodenburg, 1989). For example, the application of nonprotein nitrogen to corn at the time of ensiling could represent a cost savings over feeding soybean meal. Ionophores such as monensin and lasalocid are approved for use in dairy heifer rations in some countries. Further research is needed on methods to reduce feed costs for raising replacement heifers.

Feed Bunks for Dairy Heifers

There is a large variation in the recommended feed bunk lengths for dairy heifers of all ages. Surveys of dairy farmers found that about 50% perceive that housing is the greatest problem of calf and heifer replacement management. No documented evidence has been available to define the minimum requirements for feed bunk length that would allow the optimum growth of dairy replacement heifers. Limited feed bunk length does not adversely affect group growth rates but significantly affects individual growth rates. This may be due to increased social tension within the group and the decrease in the opportunity to obtain adequate nutrients. The following feed bunk lengths per heifer are recommended for groups of Holstein heifers fed a total mixed diet at restricted intakes at accelerated rates of gain: 15 cm for 4- to 8-month-old heifers, 31 cm for 11.5- to 15.5-month-old heifers, and 47 cm for 17- to 21-month-old heifers (Longenbach et al, 1999). At these bunk lengths, the heifers are in a harmonious group housing environment that allows them to achieve the body weight gains and skeletal growth necessary to achieve calving at 22 to 24 months of age. A high level of management is necessary to achieve uniform growth at accelerated rates of gain under these housing requirements for feed bunk length.

Water Intake

A fresh, abundant, and clean supply of water should be available before, during, and after weaning. Old or unclean water and watering systems reduce an animal's water consumption and consequently its dry matter consumption (grain and forage). Water consumption depends on several factors, including age, body size, environmental temperatures, and forage intake (Table 9-8).

Nutrition and Mammary Development

The implementation of appropriate nutritional management during the growing period can have long-term effects on dairy cow performance. The success of feeding and management programs for replacement heifers must not only be measured in terms of efficiency of body growth but, more importantly, must be assessed by milk-yield potential of the heifer. Milk-yield capacity is largely influenced by the degree of mammary development. Nutritional status

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TABLE 9-8

Drinking Water Consumption of Young Dairy Heifers

Age (mo) of Holstein Calves	Gallons (U.S.) per Day*
1	1.3-2.0
2	1.5-2.4
3	2.1-2.8
4	3.0-3.5
5	3.8-4.6
15-18	5.9-7.1
18-24	7.3-9.6

*At air temperatures of 50° to 80° F intake depends on water content of forage ration. Higher levels apply to an all-hay ration. One gallon of water (U.S.) weighs 8.34 lb (3.785 kg) and contains 3.785 L. An Imperial gallon contains 4.546 L. One cubic foot of water weighs 62.4 lb.

is critical to mammary development, especially during hormone-sensitive developmental stages, including from before puberty through to early lactation. As the emphasis on decreasing input costs and improving productivity per economic unit increases, there is pressure to reduce the length of the nonproductive period by reducing the age at first calving. Efforts to achieve younger ages at first parturition require high planes of nutrition to support rapid body growth.

High levels of feeding before puberty can adversely affect the growth of the developing mammary gland. The result can be a decrease in the size of the functional gland and in milk production when lactation commences (Sejrsen, 1978; Sejrsen et al, 1983). An average daily gain of greater than 0.7 to 0.8 kg of body weight per day during the growing period (3 to 12 months) causes a subsequent progressively declining milk yield. Heifers grown at rates above or below the optimum range may produce 10% to 20% less milk.

The effect of hormone concentration on mammary growth has been examined (Sejrsen et al, 1983). Heifers were split into two groups for restricted and ad lib amounts of a ration, and gains for each of the feeding regimens were 513 and 1218 g/day, respectively. Growth hormone was elevated for the prepubertal heifers on the restricted feed, whereas there was no difference for postpubertal heifers. Concentrations of prolactin, insulin, and glucocorticoid were higher for heifers fed ad lib than for those restricted. Mammary tissue was not related to concentrations of insulin or glucocorticoids, mammary secretory tissue was correlated positively with blood serum concentrations of growth hormone, and extra parenchymal adipose tissue was correlated negatively with them. The negative influence of excess feeding on mammary development of prepubertal heifers appears to be associated with a decrease in concentrations of growth hormone in the blood. Thus mammary tissue growth and milk production capacity in heifers are unaffected by ration energy density when heifers are raised at a low feeding level. Pubertal mammary development and subsequent milk production capacity for heifers raised on a low level of feeding are unaffected by diet energy concentration, and mammary growth in relation to puberty was correlated with circulating levels of growth hormone within heifers.

From birth to puberty, mammary tissue undergoes relatively little development. Mammary growth rate is consistent with body growth rate (isometric growth) until the onset ovarian activity preceding puberty, and increase in mammary size is mainly due to an increase in connective tissue and fat. Beginning just before the first estrous cycle (puberty), mammary parenchyma (secretory alveolar tissues) begins to grow at a faster rate than whole-body growth (allometric growth). Rapid allometric mammary growth continues for several estrous cycles and then returns to an isometric pattern until conception (Park, 1998).

Allometric growth begins again at conception and continues after parturition for variable periods of time. The majority of mammary growth occurs during pregnancy, and the rate of growth remains exponential throughout gestation. In first-calf dairy heifers, the degree of mammary parenchyma tissue development around parturition is a major determinant of milk-yield capacity during the succeeding lactation cycles. Estimates of the correlation between milk yield and mammary alveolar epithelial cell numbers range between 0.50 and 0.85. Conversely, increased proportions of fibroblasts and adipocytes in the mammary gland are associated with reduced milk yield.

Changes in feeding level (mainly energy concentration) can alter the secretion of hormones such as somatotrophin and corticoids and affect mammary growth and differentiation during hormone-dependent stages of development as growth shifts from isometric to allometric. Careful control of energy allowance during peripuberty and gestation can significantly enhance mammary growth and succeeding lactation potential of heifers.

In growing heifers, restricting energy intake delays the normal rate of mammary gland development. However, a delay in mammary gland development, controlled by dietary energy, does not impair subsequent development and differentiation of parenchymal tissue during prelactational mammogenesis, provided energy requirements are met. Restricting the energy intake of growing animals brings about physiological adaptation, whereby energy flow is redirected to energy-conserving activities, mainly maintenance and repair functions. Energy restriction also reduces certain energy-wasteful metabolic systems, which may not be metabolically essential for growth and maintenance.

Realimentation following energy restriction induces compensatory growth, which is characterized by accelerated metabolism, reduced maintenance requirement by depression of the basic metabolic rate, activated endocrine status, and altered tissue composition of mammary gland.

A well-controlled nutrition regimen during the hormone-sensitive growth phase before first parturition can significantly affect mammary growth, differentiation, and performance at subsequent lactations. A time-dependent and nutritionally induced compensatory growth favorably alters the physiological development and differentiation of the mammary gland as well as the lactation potential. A stair-step nutrition regimen, proposed for developing dairy heifers, is a combination of both energy restriction and realimentation designed to induce compensatory mammary growth, which coincides with different developmental states (Park, 1998). A controlled stair-step compensatory nutrition model can enhance the growth potential of heifers. The controlled nutrition regimen encompassing both restriction and refeeding during the early peripubertal developmental stages has positive effects on mammary growth and milk yield potential. During the energy-restriction phase, the rate of growth lags behind the body weight of traditionally fed animals. During the energy realimentation phase following

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energy restriction, animals consume energy far in excess of that needed for maintenance, thereby redirecting the energy flow to the metabolic process of growth. Thus these animals exhibit an accelerated rate of growth that exceeds the normal growth curve. The extent of mammary hyperplasia and hypertrophy induced by a compensatory nutrition regimen is clearly reflected in the higher nucleic acid and protein content of the tissue (Park, 1998). A stair-step feeding program can be adapted to management practices of average to large sized farms.

An alternating *3-2-4-2-5-2-month stair-step nutrition model* for dairy heifers has been described (Park, 1998). Holstein heifer calves, weighing an average of 160 kg (at approximately 6 months of age), were compared with control heifers offered ad libitum access to a diet meeting the nutrient requirements recommended by the NRC (1989) and adjusted for an age at first calving of 24 months and liveweight gain of 0.78 kg/day. During the first stair-step, which lasted for 3 months (from 6 to 9 months of age) and encompassed the prepubertal period, the stair-step heifers were fed on a diet formulated to reduce the intake of metabolizable energy by 30%. Protein supply was maintained at levels recommended by the NRC (1989) by increasing the crude protein from 120 to 170 g/kg dry matter. Following 3 months of energy restriction, the heifers received a realimentation diet (1.3 times the metabolizable energy) for 2 months (from 9 to 11 months of age). Compensatory growth occurred during this allometric phase of mammary development. The second step (puberty and breeding) consisted of energy restriction for 4 months (11 to 15 months of age) followed by realimentation for 2 months (15 to 17 months of age). In the third and final step, energy was restricted for 5 months (17 to 22 months) followed by realimentation for 2 months (22 to 24 months of age). Overall, the stair-step heifers received an average of 0.9 of the energy allowance given to the control group. Both low-energy and realimentation diets were formulated to provide intakes of protein, vitamins, and minerals equal to the control diet, except energy intake that was varied. Heifers were bred during the second realimentation period (16 months of age) to calve at approximately 24 months of age.

Heifers raised on the stair-step feeding program responded with characteristic compensatory changes. They gained more body weight and consumed less feed than heifers fed conventionally. Live-weight gains were depressed during the period of energy restriction, but recovery occurred during the realimentation phase, causing significant improvements overall in feed, energy, and protein conversion ratios. In summary, a controlled stair-step compensatory nutrition program can enhance the growth potential of heifers. During the energy-restriction phase, the rate of growth lags behind the body weight of traditionally fed animals. During the energy realimentation phase following energy restriction, animals consume energy in excess of that needed for maintenance, thereby redirecting the energy flow to the metabolic process of growth. Thus these animals exhibit an accelerated rate of growth that exceeds the normal growth curve.

The compensatory nutrition feeding program causes mammary hyperplasia and hypertrophy and increased expression of the major milk protein genes, indicating increased mammary differentiation and functional activity in mammary tissues. Heifers on the compensatory program had 1.05 times the total protein and 1.15 times the casein in milk than the control heifers (Park, 1998). Lactation performance is significantly enhanced in cows reared on a stair-step feeding program compared with those fed according to the linear growth curve of the NRC (1989). Stair-step heifers produce 1.1 times the milk of conventionally-reared compared with control animals which increase represents about 900 kg milk over 250 days.

In summary, a controlled nutrition program, including both restriction and refeeding during early peripubertal developmental stages, has positive effects on mammary growth and milk yield potential. The dietary restriction consists of a reduction in energy (caloric intake) while providing an adequate supply of other essential nutrients (protein, vitamins and minerals). The fundamental concept of the stair-step compensatory nutrition program is to favorably exploit the nature of both dietary energy restriction and the compensatory growth phenomenon in concert with one or more hormone-dependent phases of mammary development.

The observation of differences among rates of mammary secretory tissue development has led to the concept of a "critical period" of mammary development (Sejrsen et al 1982). Ad lib feeding during prepuberty lowered mammary secretory tissue weights 23% and DNA content 32% compared with restricted feeding. In contrast, there was no difference in growth of mammary secretory tissue between postpubertal heifers fed restricted or ad libitum amounts. Composition of mammary parenchyma was not affected by plane of nutrition in prepubertal or postpubertal heifers. Because of this, a critical period was suggested for total mammary cell numbers in heifers during which mammary growth is affected adversely by a higher plane of nutrition. A heifer's capacity to produce milk is decreased when the plane of nutrition causes daily gains larger than 700 and 500 g in heifers of the large and small dairy breeds, respectively. In contrast, milk production is enhanced if the plane of nutrition after the critical period supported daily gain larger than 600 g in heifers of the large dairy breeds. Heifers that are reared on a high plane of nutrition during the critical period have a permanently-reduced content of parenchyma in the mammary gland. The positive effect of plane of nutrition after the critical period appears to be related to an increase in mammary size and feed intake that corresponds to the increase in body size and improved body condition. The decrease in milk production has also been shown to occur with overall increases in nutrient intakes and not solely increased energy intakes (Lammers et al, 1999). At the farm management level, careful attention to nutrition and growth from postweaning to puberty is crucial to maximizing the productive potential of replacement heifers. Lifetime productivity of dairy cows is affected by age at first calving, and this is closely related to the age at puberty onset.

Monitoring Replacement Heifer Nutritional Management

Charting Growth. On many dairy farms, heifer management is not the most critical part of the day-to-day activities, and chronic neglect of nutrition, feeding management, and health management can lead to suboptimal growth. This leads to heifers that calve much later than 24 months of age and that produce considerably less milk during their lifetime than those properly fed and well grown. Not only are undersized heifers smaller and less productive, but they also are prone to more problems at calving. On the other hand, accelerating the growth of heifers until they become fat also reduces their lifetime milk production and longevity. Overfeeding concentrates or high-quality forages such as corn silage can cause this condition.

An assessment of a replacement nutritional management program can be made by monitoring heifer growth (Donovan and Braun, 1987). Weight can be monitored by taking an actual calibrated scale measurement or an estimate from a heart girth tape and conversion chart. Skeletal growth is as-

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sessed by taking measurements of height at withers. These data can be plotted on prepared charts to evaluate the growth patterns of individual heifers or to assess growth in the replacement herd. In Pennsylvania, in one field trial, 5723 heifers on 163 farms were measured regularly to develop growth charts that represent the normal patterns of growth for Holstein heifers under commercial dairy management conditions (Heinrichs and Hargrove, 1987). Later data were collected from the National Dairy Heifer Evaluation Project that represents a U.S. population of Holstein heifers (Heinrichs and Losinger, 1998). Increased rolling herd average milk production is associated with greater growth among Holstein dairy heifers. The practice of feeding fresh or sour colostrum to heifers from 24 hours of age to weaning was also related to greater growth. Regionally, dairy heifer body weight was greatest in herds in the Midwest and least in the Southwest United States. It is suggested that differences in feeding strategies in various regions of the United States may explain the different growth rates.

The objective of a heifer-raising program is to achieve a relatively constant rate of growth. Holstein heifers should reach 750 to 800 lb (340 to 362 kg) and 48 to 50 in (122 to 127 cm) by the desired breeding age of 13 to 15 months. After calving, heifers should weigh 1137 to 1296 lb (515 to 587 kg) and measure 52 to 54 in (132 to 137 cm) tall at the withers. The recommended breeding heights and weights for all heifers are shown in Table 9-9.

Optimum Body Size of Heifer Replacements. There is a positive relationship between body weight at first calving and first lactation yield, which has been the basis for using live body weight to define body size of replacement heifers (Hoffman, 1997). However, live body weight is not the only available measurement to define body size. Skeletal measurements such as wither height, length, and pelvic area are related to first lactation performance or dystocia. Weight at calving is highly heritable but not correlated genetically with milk yield (Lee, 1997). Genetics determines the inherent potential of an embryo to grow into a highly profitable cow. Feeding and management determines the extent to which that potential will be realized. Heifers under one year of age should be fed to maximize growth without excess body condition. Better feeding of pregnant heifers can add body condition but cannot compensate for lack of early real growth in size.

Growth Charts. The summaries of measuring a large number of heifers of various breeds throughout the United States are illustrated in Figs. 9-4 to 9-10. The Holstein population was part of a nationwide USDA study conducted during 1991 and 1992 (Heinrichs and Losinger, 1998). Most of the data were collected from herds in which the average age at first calving was slightly greater than 24 months. As a result the heifers probably were smaller for any given age than those found on today's well-managed dairy farms that calve heifers at 22 to 24 months of age.

The Holstein heifer growth charts illustrate several percentiles of the U.S. population, allowing a producer to compare an individual heifer with all others and to set growth goals. Previous research has shown that heifers large enough to calve at 22 to 24 months old with acceptable levels of milk production must be near or above average in size (Figs. 9-4 and 9-5). Producers should remember that producing extremely large heifers may not cause increased levels of lifetime milk production and is expensive from a feeding perspective because of the larger animals' increased daily calorie requirements.

Age at calving is highly correlated to the profitability of the animal, and that body weight after calving (1250 lb [567 kg] for Holsteins) is highly correlated to first lactation milk production. An achievable goal for dairy producers or contract heifer raisers is to keep a majority of heifers near the 75th percentile and the entire herd ranging between the median and the 95th percentile. Under Dutch farming conditions, the optimum rearing strategy caused an average calving age of 22.6 months at a calving weight of 564 kg (Mourits et al, 1999)

For all breeds of heifers except Holsteins, the recommended growth ranges shown are between the average and the top 67th percentile of the population. To achieve early calving (24 months or less) and high production potential, individual heifers should fall near the top of or slightly above the shaded area. Readers can interpret from these graphs that the height at the withers is more variable for younger heifers and, in general, that the variability in weight increases as age increases. Breed standards developed from the measurements of Jersey, Ayrshire, Brown Swiss, Guernsey, and Milking Shorthorn were all done within the past 10 years (Figs. 9-6 to 9-10).

Evaluating Growth Charts. Growth charts can aid in the evaluation of the performance of a heifer management program and can alert the producer to problems such as entire groups of animals being undersized, underweight, or overweight. Low- or poor-quality forages (hay and silage) generally are responsible for inferior growth performance in young heifers, but lack of a balanced grain supplement and overcrowded housing can add to the problem. Underfed calves typically do not receive adequate energy and protein to meet their growth requirements. Inadequate housing and ventilation can contribute to poor growth by causing subclinical respiratory problems and can negate an adequate feeding program. The level of management and sanitation also can affect heifer growth.

Adequate weight but restricted skeletal growth may occur in a particular age group. This usually is caused by relying

TABLE 9-9

Suggested Weights and Heights for Breeding Age Heifers

Breed	Body Weight (lb)/(kg)	Wither Height (in)/(cm)	Hip Height (in)/(cm)
Holstein	750-800 (340-362)	48-50 (122-127)	50-52 (127-132)
Jersey	525-575 (238-260)	43-45 (109-114)	45-47 (114-119)
Ayrshire	700-750 (317-340)	46-48 (117-122)	48-50 (122-127)
Guernsey	700-750 (317-340)	46-49 (117-124)	48-51 (122-129)
Brown Swiss	750-800 (340-362)	48-51 (122-129)	50-53 (127-135)
Milking Shorthorn	750-800 (340-362)	46-48 (117-122)	48-50 (122-127)

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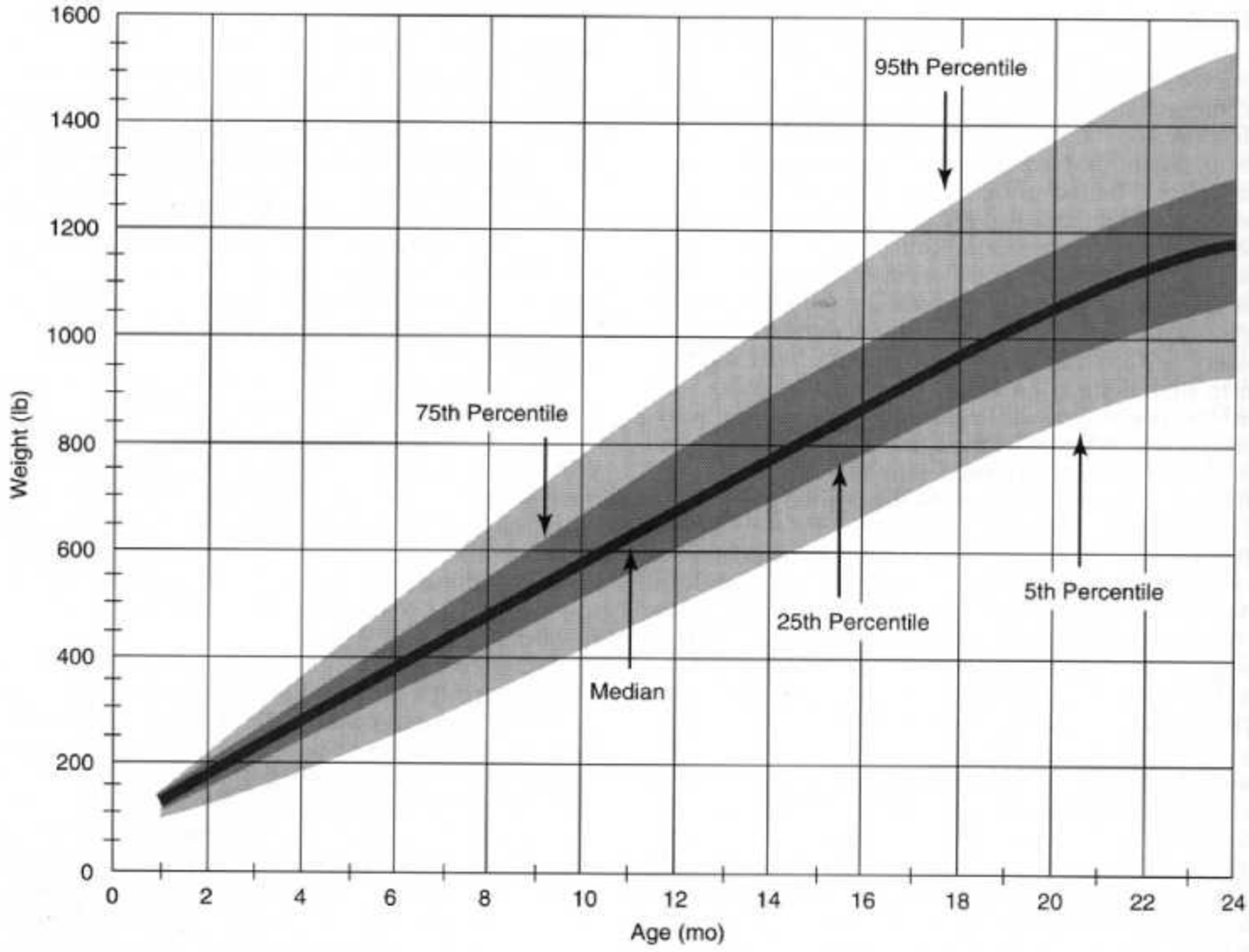

FIG. 9-4 Weight by month of age: U.S. Holsteins.

on poor-quality hay and corn silage for all or most of the diet. Both of these forages typically have low protein, mineral, and vitamin levels. Feeding cereal grains with very little protein, mineral, and vitamin supplementation along with these forages may exacerbate the problem. Feeding 2 to 4 lb of grain per day and balancing the diet for protein, energy, minerals, and vitamins can solve a feeding problem, often within several months. Rations must be more nutrient dense if heifers are to compensate with increased growth rates.

Another common scenario involves overweight animals with fairly normal skeletal growth for a specific age group. Heifers as young as 6 to 8 months of age may appear fat, but the problem generally is more common in breeding-age heifers. This condition most often is caused by marginal to adequate dietary protein but excessive energy intake. This can result from free-choice corn silage feeding along with moderate levels of supplemental grain, and it arises on farms where good- to excellent-quality forages are produced and unrestricted amounts are fed to the heifers. Restricting the feed intake of these high-quality forages usually corrects the problem.

Computer spreadsheet and database programs are available for monitoring heifer growth. One such program analyzes individual heifer growth and herd averages as deviations from the expected growth patterns found in Pennsylvania (Ehrlich and Heinrichs, 1989). The computerized methods are recommended for maintaining an ongoing bank of information on replacement heifers in a herd and for making long-term management decisions. In summary, monitoring growth is the key step to starting the health management cycle for nutritional management of replacement heifers.

Monitoring Body Condition Score. Body condition scoring is an additional aid that can be used to evaluate the overall nutrition and management of a heifer program. Some limitations in conducting heifer body condition scoring include long winter hair coats (in colder climates) and the problem of assembling and restraining heifers to closely observe fat over the ribs and tail head.

The recommended range of body condition scores for heifers is illustrated in Fig. 9-11. Young calves generally are thin naturally (2.0 to 2.5 on the five-point scale), but their body condition score should increase to or near 3.0 by breeding age. A body condition score of 3.5 to 3.7 is considered ideal for heifers calving at age 22 to 24 months. This score allows a moderate amount of stored body fat to be used in early lactation when dietary energy is insufficient for milk output.

Housing for Replacement Dairy Heifers

Housing recommendations for dairy calves up to weaning were reviewed earlier in this chapter. This feature of calf management has been studied extensively, and its relationship to the morbidity, mortality, and growth of neonatal calves has been described. Data and conclusions regarding the housing of postweaning replacement heifers are not as abundant. A major step in heifer rearing is the process of weaning and the movement of calves from individual to

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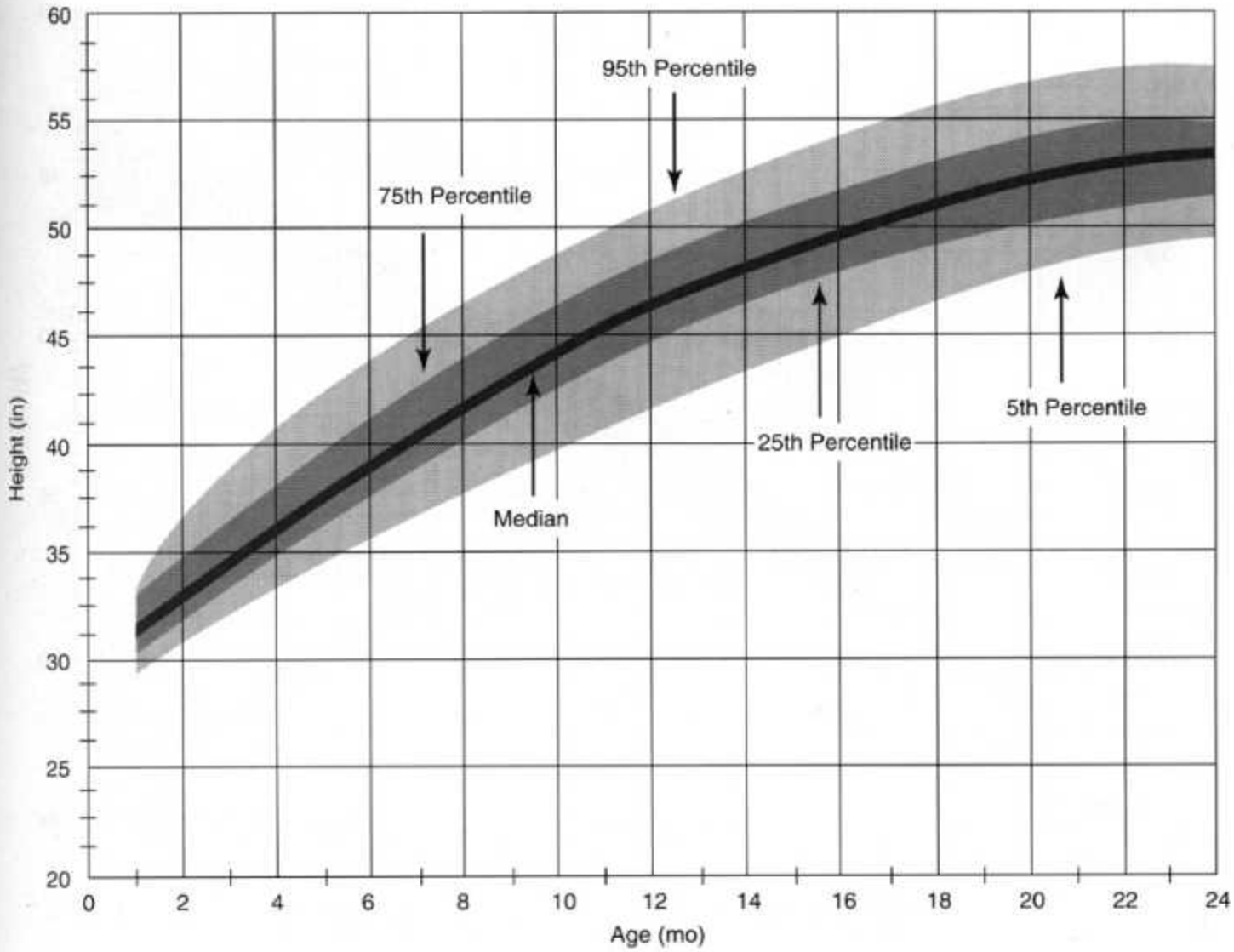

FIG. 9-5 Height by month of age: U.S. Holsteins.

BOX 9-2

Components of Housing for Heifers

Grouping capabilities by age and size for at least three to five separate groups
Ease of movement of animals between groups and to restraint facilities
Restraint facilities for breeding and health care
Ease of observation
Ease of cleaning and adding bedding as needed
Continuous water supply
Adequate ventilation

group housing. This transition step is especially important for calves moved from individual hutch housing systems to group pens for growing heifers. Housing for heifers from the weaning pen to calving must provide some rather simple yet important components (Box 9-2).

Current Status of Replacement Heifer Housing

In a survey of calf and heifer housing on Pennsylvania dairy farms, over 70% of farms moved newly weaned calves to loose-housing group pens or to superhutches for a group of calves (Heinrichs et al, 1987a). However, over 50% of the heifer housing facilities were located within direct contact with the milking herd. A large percentage of farms were mixing newly weaned calves with older heifers, and 13.7% of farms did not group heifers by age or size. Although the average group size was 6.3, the groups often contained too many heifers of a wide age range. In small dairy herds, it was common for heifers to be housed in stanchions. In summary, the recommendations for housing and grouping dairy replacement heifers were not often followed (Graves and Heinrichs, 1989). The most commonly cited reasons were insufficient housing space and uneven age distributions (Heinrichs et al, 1987a).

In the same study in Pennsylvania, the adequacy of ventilation systems was assessed. Air exchange was often not adequate, particularly for younger calves. The survey found that producers interpreted the term "natural ventilation" to mean a structure with no ventilation system. The major problems that farmers perceived with their own farms and those of their neighbors in relation to replacement heifer housing were *overcrowding* and *inadequate ventilation*.

Only 31% of the herds surveyed had some type of restraint facility for replacement heifers (Heinrichs et al, 1987a). The restraint systems in use included head gates, stanchions, and other approaches, such as behind a gate. A functional restraint system is an integral requirement for the adoption of AI and intensive health management programs for replacement heifers (Graves and Heinrichs, 1989).

A state-wide extension program on dairy replacements directed at dairy farmers, agribusiness, veterinarians, and others in frequent contact with dairy farmers found that 85% of

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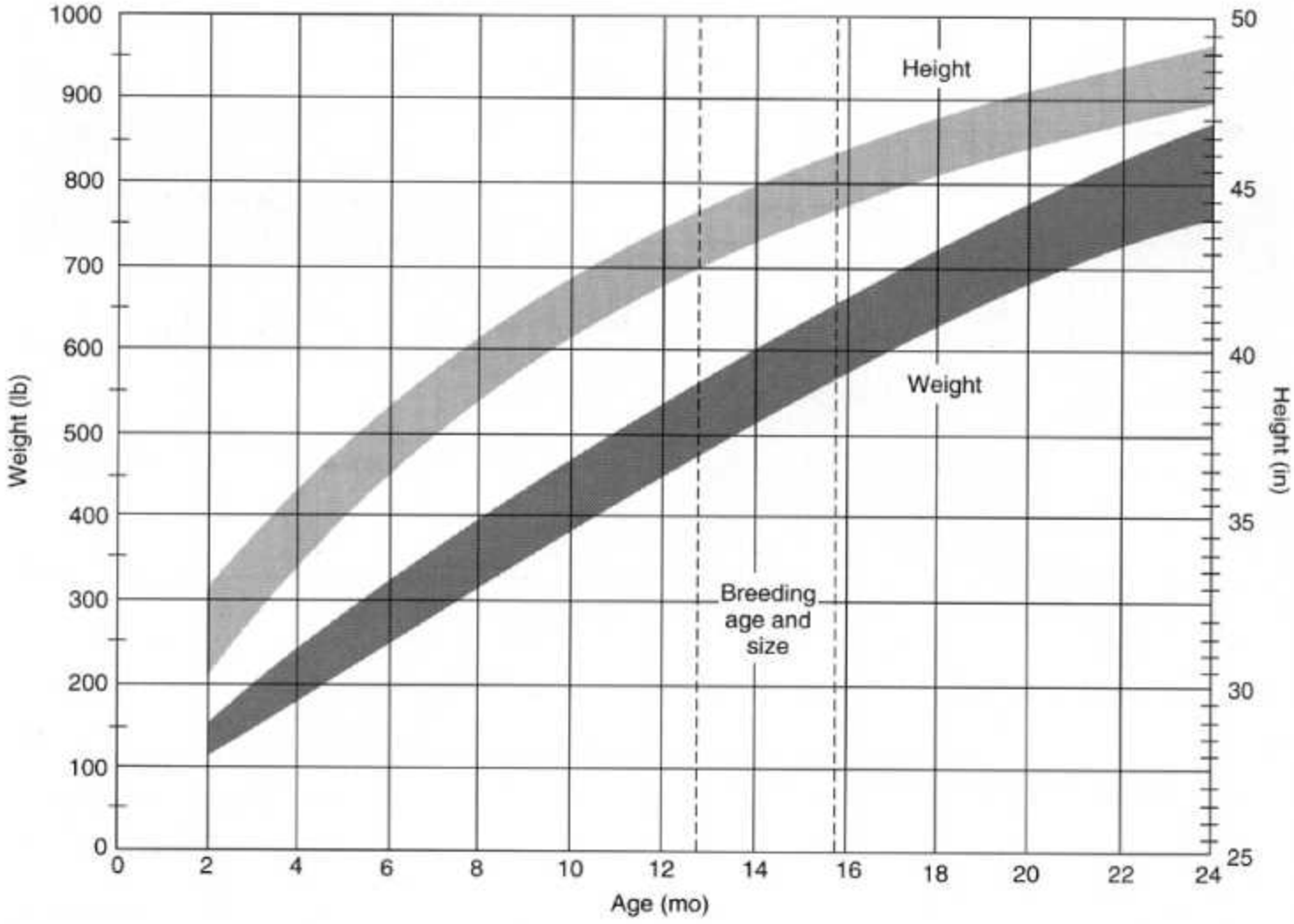

FIG. 9-6 Penn State calf and heifer growth chart: Jersey.

the farmers in the original random sample learned new information about calf and heifer management during the project, and 77% reported that they received all or part of this new information from extension (Heinrichs and Kiernan, 1994). Sources of information most often used by farmers in the study were dairy magazines, extension newsletters, and meetings organized through either extension or agribusiness. Adoption by farmers of many of the targeted practices specific to calving management, preweaned calves, and health management increased over the period of extension activity.

Surveys of dairy farms in Australia have found that there is much opportunity to improve the rearing of dairy heifer replacements (Hough and Sawyer, 1993; Moran et al, 1996).

In summary, current replacement heifer housing systems often do not create an environment conducive to optimum health and performance. Although the recommended approaches to housing heifers are well known, the adoption of these practices is not widespread and more focused extension efforts are needed. Veterinarians may overestimate their services in providing advice about heifer rearing compared with what the herd owners perceive (Giger et al, 1994). There are many opportunities for veterinarians who are providing a health management service to dairy producer to provide advice on housing and ventilation systems for heifer replacement rearing.

Principles and Recommendations for Housing Calves After Weaning

A special effort should be made to reduce the stress on calves before, during, and immediately after the weaning process. The facility should be clean, dry, and draft-free and should ensure isolation from the milking herd or older replacement heifers. A small group housing system to accommodate three to five calves per group should be used for at least 1 month after weaning. Because hutch housing systems are commonly recommended for young calves, a structure termed a "super-hutch" is a desirable system (Graves and Heinrichs, 1989). These small buildings accommodate three to five calves, are movable, and require minimal normal labor to manage.

The location of the postweaning housing is important for frequent observation of the recently moved calves so that animals not adapting well to the new situation can be detected early. Submissive calves that are easily pushed away may need extra attention to ensure adequate feed and water intake. The rates of clinical disease in a herd may affect the frequency of calves not adapting well (Waltner-Toews et al, 1986f).

The process of weaning should take place 2 to 4 weeks before changing locations. The types of forage and grain should remain constant throughout this period. The availability of a continuous supply of frost-free water is important. At least 0.45-m bunk space, with stanchions, head gates, or dividers to define eating positions, promotes optimum feed intake. The group pen should allow for approximately 3 m^2/calf for adequate comfort. In Danish commercial dairy farms, both welfare and production were improved in heifers with access to 2.7 to 3.6 m^2 compared with 1.8 m^2 resting area per heifer (Morgensen et al, 1997). Increasing the resting area from 1.8 m^2 to 2.7 or 3.6 m^2/heifer improves the welfare of group housed dairy heifers (Nielsen et al, 1997).

Free-stall housing is not recommended for calves up to 4 months of age. The requirements for minimum area per animal, minimum feed bunk space per animal, suggested free-stall size, and appropriate watering methods are given in Table 9-10), as are the recommended maximum number of

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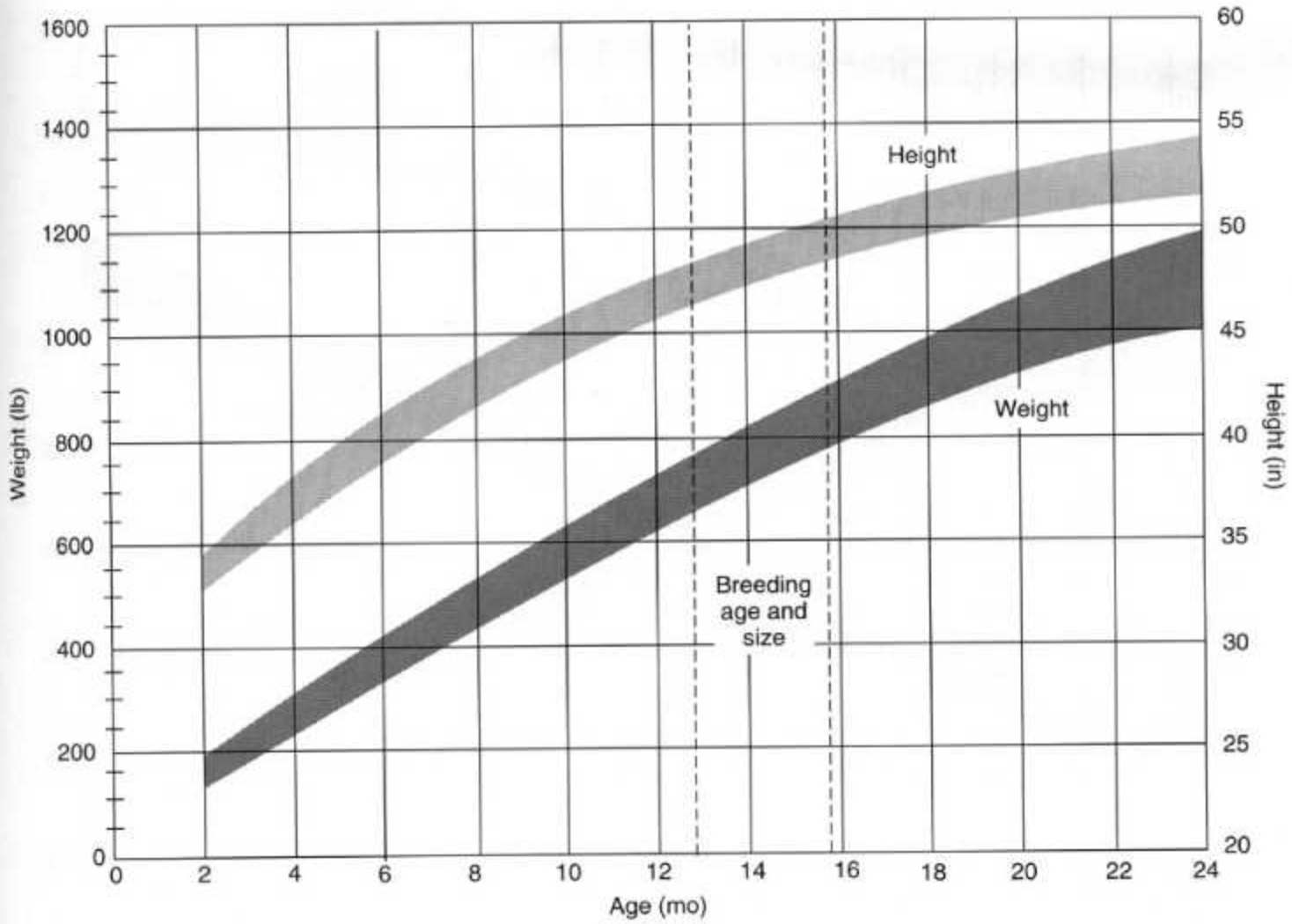

FIG. 9-7 Penn State calf and heifer growth chart: Guernsey.

animals, maximum age spread, and maximum weight variation per group (Heinrichs et al, 1987a). Compliance with these recommendations can promote environmental conditions that lead to desirable levels of health and performance in dairy replacement herds.

Air quality is a critical issue for indoor housing systems. The health and performance of postweaned calves raised in conventional indoor group pens have not been compared with those raised in naturally ventilated units in controlled experiments. Natural ventilation offers considerable advantages in energy efficiency and operator comfort. Although improvements in animal health and performance are expected with the use of natural ventilation systems, further documentation is necessary.

The Missouri system of dairy heifer production consists of four phases of development: birth to 2 months, during which calves are housed in individual hutches; 2 to 4 months, when raised in free-stall barns; and 6 to 12 and 12 to 24 months, when calves are on rotational pasture systems with supplemental feeding (Randle et al, 1998). Guidelines are available for site selection, animal flow, breeding, health management, and husbandry and feeding management.

Principles and Recommendations for Housing Growing and Bred Heifers

The key to the health and performance of growing and bred replacement heifers lies in the ability to change the forage:grain ratios in the ration according to age and size. Housing is crucial in allowing for the appropriate grouping of heifers. The housing system should permit easy, uneventful movement from group to group according to growth. Small groups of 6 to 12 heifers are most desirable. The facility should allow frequent observation, minimal labor for manure removal and addition of bedding, continually available frost-free water, and natural ventilation.

Several designs of yearling heifer facilities allow for the implementation of appropriate health management principles (Graves and Heinrichs, 1989). If a new facility is to be constructed, a commonly recommended design is an open front or gated bedded pack heifer barn (Graves and Heinrichs, 1989; Stone, 1987). This barn type has distinct advantages for convenience of observation, ease of movement from group to group, and ability to install adjustable, self-locking head gates to accommodate each heifer in the pen. The effectiveness of AI and health management program options improve dramatically with the installation of automatic restraint devices (Heinrichs et al, 1987a).

Good-quality pasture represents an excellent, cost-efficient system of nutrition for replacement heifers, particularly after pregnancy has been confirmed. In most climatic regions a three-sided open front barn or some other adequate type of shelter is necessary for protection from precipitation and wind. In addition, provisions must be made for supplemental feeding, depending on the pasture quality. Portable hay racks, silage wagons, or round bale feeders are some options available to provide additional feed. The use of pasture systems may affect health management requirements, such as appropriate parasite control and vaccination programs.

Monitoring Effectiveness of Replacement Heifer Housing Systems

The adequacy and effectiveness of replacement heifer housing systems can be monitored reliably with indexes of health and performance. The charting of growth, as previously described, is a good indicator of housing suitability. The calculation of age-specific and disease-specific morbidity and

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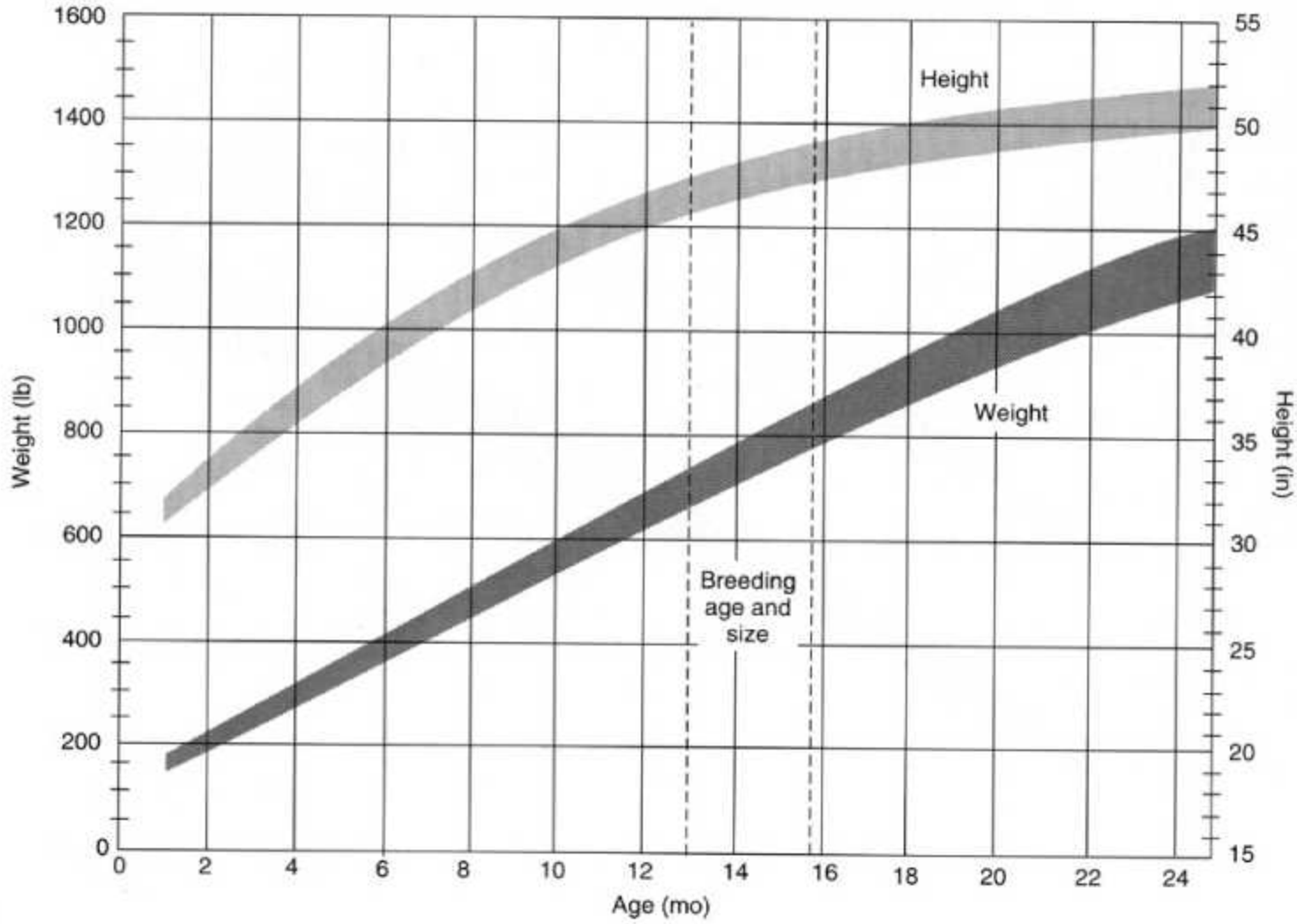

FIG. 9-8 Penn State calf and heifer growth chart: Ayrshire.

mortality rates can effectively monitor the adequacy of a housing system to provide an environment that reduces the risk of clinical and subclinical disease. The specific methods of calculation and interpretation of these indexes have been covered in previous chapters and are reemphasized in disease control for replacement heifers.

Reproductive Performance in Replacement Dairy Heifers

The major objectives of the reproductive performance program of replacement dairy heifers is to achieve an economically appropriate age at first calving and to have a minimum rate of dystocia at first parturition.

Age at First Calving

The current status and trends over time in age at first calving of dairy heifers have been examined (Nieuwhof et al, 1989; Powell, 1985). For each of the six major dairy breeds, the average age at first calving did not change appreciably between 1960 and 1982 (Powell, 1985). For example, in 1960, the mean age at first calving of 54,444 Holstein heifers was 27.2 months. In 1982, 485,200 Holstein heifers averaged 27.3 months of age at first parturition. The frequency distribution was skewed to the left. For unexplained reasons, all breeds had their highest mean age at first calving in 1976. Also, there was a seasonal association with age at first calving. Heifers born in the period from January to March of each year averaged 0.5 months older at first calving than those born in August and September. There were consistent differences among breeds. Jersey heifers had an overall average age at first parturition of 26.2 months for the 22-year period studied as compared with an average of 28.6 months for Ayrshire heifers. The average ages for Holstein, Guernsey, Brown Swiss, and milking shorthorns were intermediate.

The important issue is the relationship of age at first calving to productivity and profitability. This relationship has been studied in two ways. Observational studies of field data involving large populations of dairy heifers have been reported (Little and Kay, 1979). As age at first calving increased, lifetime production and herd life span decreased. Heifers that calved at a younger age had lower production in first lactation. However, their production per day of herd life and lifetime total yields ended up to be significantly higher than heifers that calved at an older age.

The decision to begin breeding heifers is often based on weight, body size, and age, or on a combination of these factors. Thus the use of observational studies from DHIA field data to assess the effects of breeding age may be confounded by growth rate and reproductive performance. To validate the observational studies, experiments have been designed specifically to compare two groups of heifers prospectively that were randomly assigned for breeding to calve at different ages. In these studies the late calving group had slightly better first-lactation performance than the early calving group (Lin et al, 1986). These differences did not carry over to the second and third lactations. The early calving group had more productive days, produced greater total yield, and yielded more per day of herd life (Lin et al, 1986, 1988). In addition, calving ease, reproductive performance, and health data were not different among the groups.

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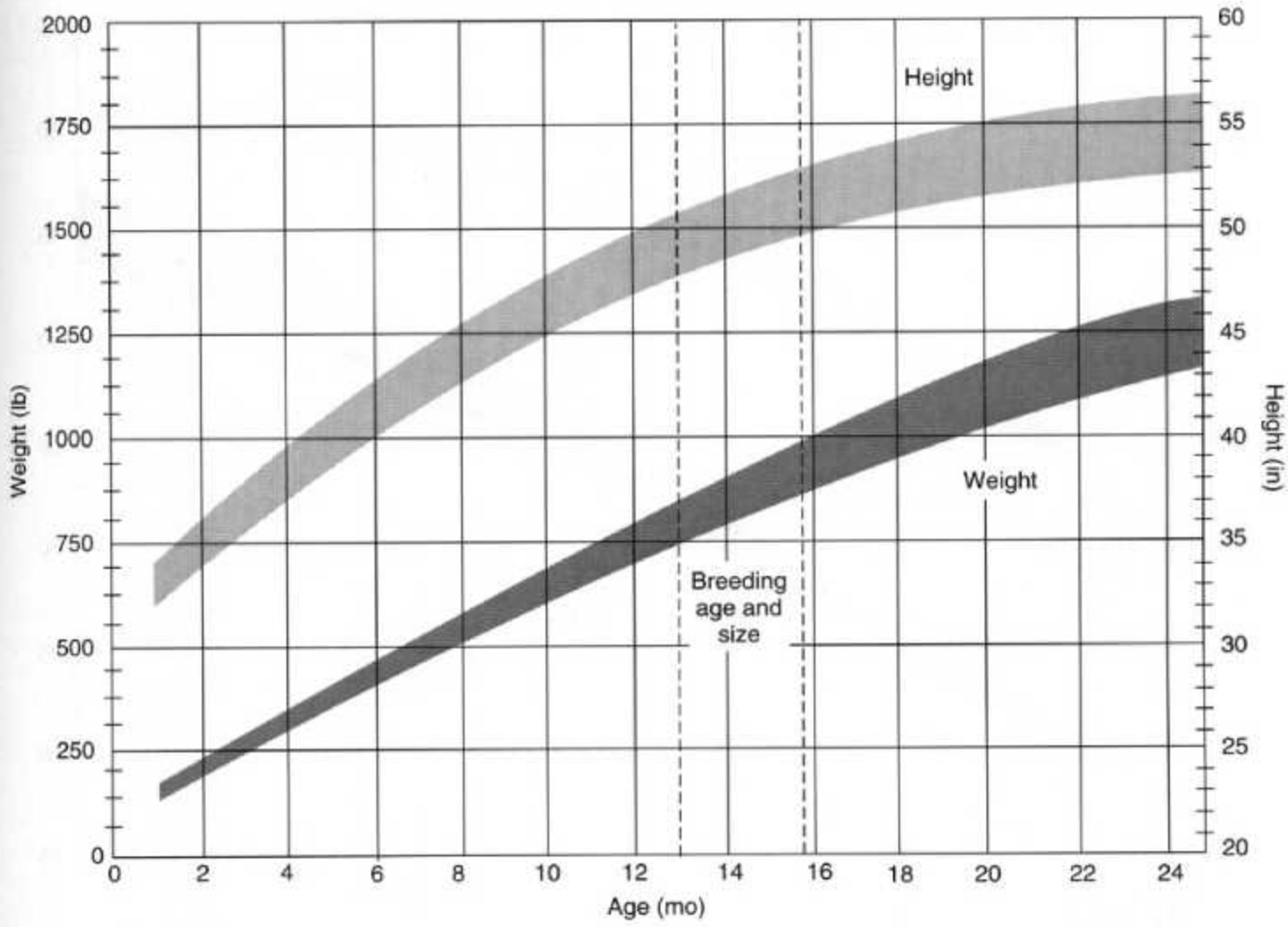

FIG. 9-9 Penn State calf and heifer growth chart: Brown Swiss.

The results of these observational studies and prospective field trials have led to the conclusion that there would be substantial economic benefit for the dairy industry in reducing the age at first calving. Only 50% of 948 Holstein replacement heifers from 21 herds in New York State had calved by 30 months of age (Correa et al, 1988), even though the objectives of their replacement management program had stated goals that were much younger than this age (Curtis, 1986).

Effects of calfhood morbidity on age at first calving have been documented (Correa et al, 1988). Heifers without respiratory illness were twice as likely to enter first lactation compared with heifers treated for respiratory disease as calves. In addition, average age at first calving was 6 months younger for calves without respiratory illness. Heifers with nonspecific illness characterized by dullness were 1.6 times more likely to calve and calved 2 months earlier than calves that did not have dullness. Waltner-Toews et al (1986f) studied survival to maturity and age at first calving in heifer calves from 34 Holstein dairy farms in southwestern Ontario. Heifers treated for diarrhea as calves were found to be 2.9 times more likely to calve after 900 days of age than were nonaffected calves.

In a study of 1161 Holstein-Friesian heifers from 22 Michigan dairy herds, age at first calving was not related significantly to either milk production or reproductive efficiency. However, heifers calving at an older age (>750 days of age) had greater problems with dystocia and ketosis. It was concluded that the managers of these Michigan herds should attempt to lower the age at first calving (Van Dam et al, 1988).

Dairy replacement heifer programs should strive to achieve a target of 24 months for average age at first calving for their herds (Donovan and Braun, 1987). It is clear from previous research that this objective is difficult to achieve with suboptimal health management practices and that proactive strategies may have to be implemented. Most DHIA record processing centers provide this index. Otherwise, age at first calving can be calculated easily from manual records.

Under grazing conditions in New Zealand, it is suggested that dairy heifers should reach 60% mature weight by 15 months of age for optimum fertility at first breeding, and 90% mature weight by 22 months for optimum milk solids production in the first lactation (Penno et al, 1994, 1997).

Calving Ease

Being able to get dairy heifers into production in their first lactation, without a significant problem at parturition such as dystocia, is a major goal of replacement rearing programs. Dystocia, defined as delayed and difficult parturition, has a major economic impact on the dairy cattle industry (Berger, 1994). In addition, the significant economic loss from calf stillbirth associated because of a high incidence of dystocia is undesirable.

An additional 14 days open and a decrease of 654 kg in milk production was found in cows with extreme calving difficulty compared with no calving difficulty (Djemali et al, 1987b). A decreased milk yield in first lactation following a difficult birth, at an estimated minimum cost for each assisted delivery in heifers of $50 to $60 (U.S.) has also been reported (McDaniel, 1981).

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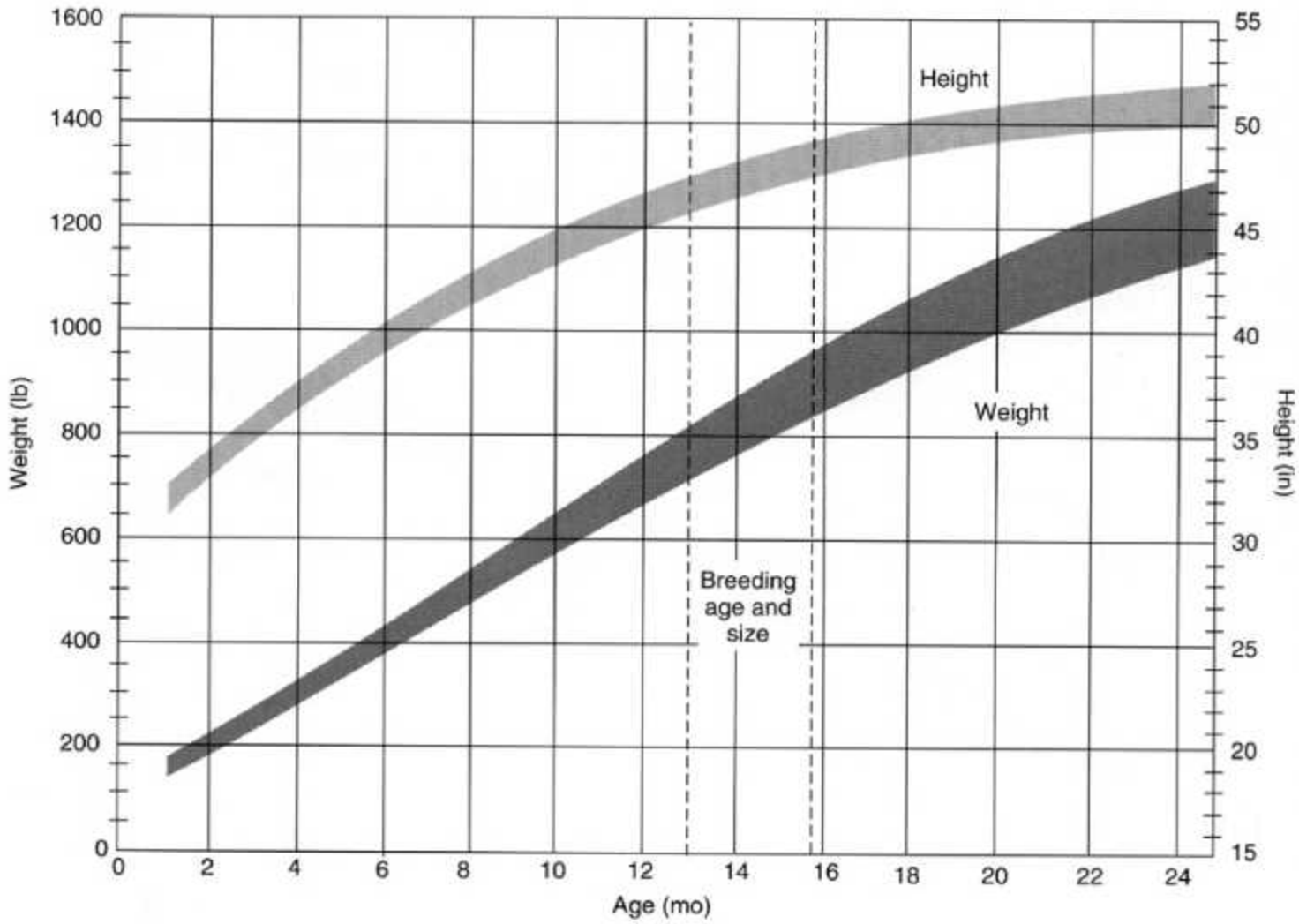

FIG. 9-10 Penn State calf and heifer growth chart: Milking Shorthorn.

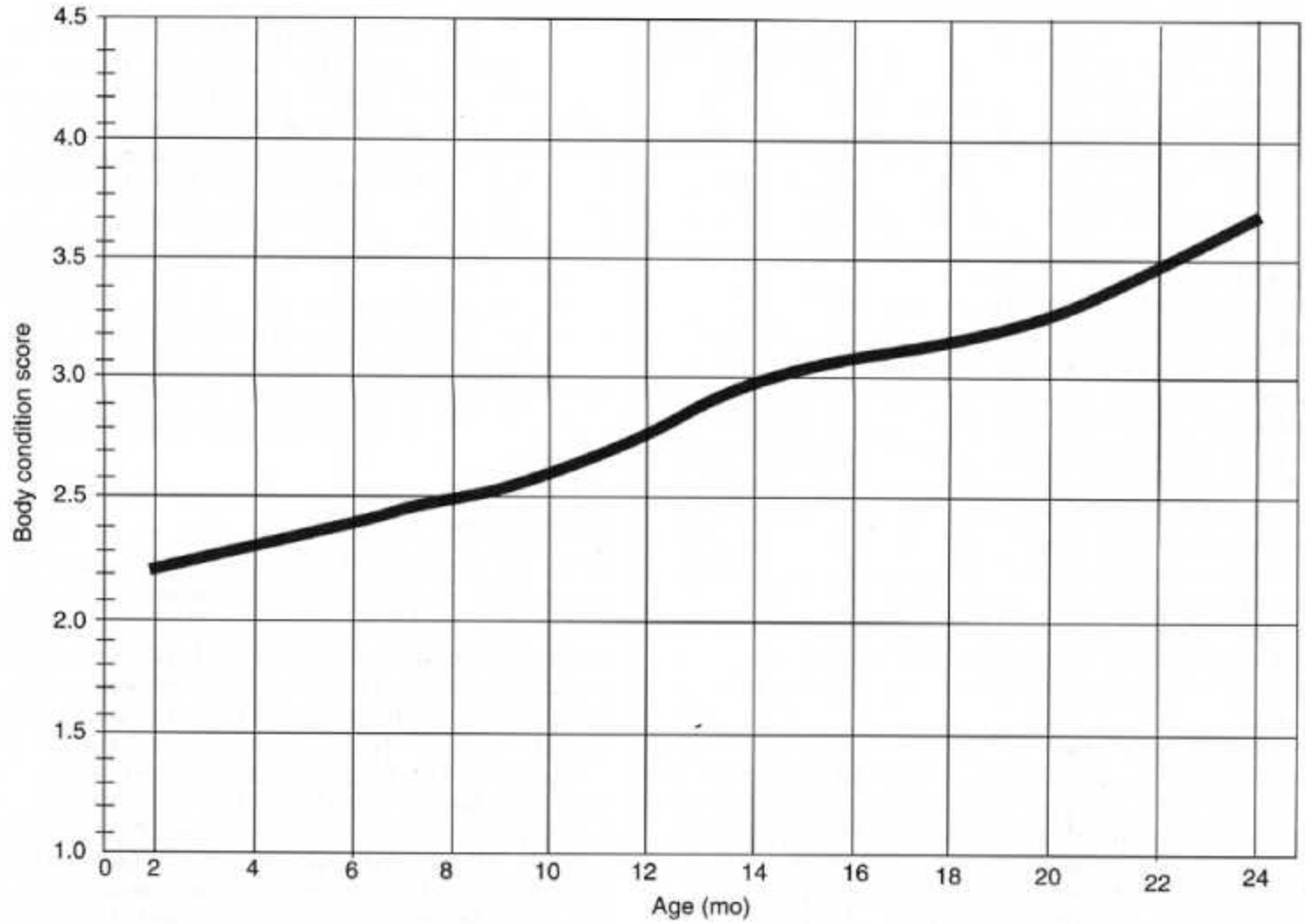

FIG. 9-11 Body condition score: dairy Holstein.

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TABLE 9-10

Calf and Heifer Housing Requirements

Group*	Age (mo)	Maximum Animals per Group	Maximum Age Spread in Group	Maximum Weight Variation in Group (lb)	Minimum Pen or Pack Area per Animal (ft^2)	Minimum Feed Bunk Length (in) per Animal†	Suggested Free Stall Size (Width × Length, in)	Water	Restraint Facilities
1	0 to 2	1			24 to 32	Individual grain pail	Not recommended	Individual pail	
2	2 to 4	3 to 5	3 wk		30	Hay rack 18 inches with dividers	Not recommended	Continuously available frost-proof water	Stanchion
3	4 to 6	6 to 12	2 mo	75	30	15	27 × 48		Self-closing fence line or chute and stanchion or head gate
4	6 to 9	10 to 20	150	150	30	15	30 × 54		
5	9 to 12	10 to 20	3 mo	200	30	18	34 × 60		
6	12 to 18	10 to 20	6 mo	300	40	20	38 × 72		
7	18 mo to calving	10 to 20	6 mo	300	40	22	42 × 84		

From Heinrichs AJ, Swartz LA, Hutchinson LJ, et al: *Penn State Ext Circ* 385:18-32, 1989.

*Groups 4 to 7 may be combined in one form or another when the total number of heifers is small. When selecting which groups to combine, consider feeding requirements, management needs, and size or age of animals.

†Feed bunk space per animal may be reduced approximately 20% in groups over 6 months of age if total mixed rations are fed.

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Dystocia rates for first-lactation Holstein heifers have been reported to be approximately 10% to 11% (Van Dam et al, 1988; Cue and Hayes, 1985). Calving difficulty, stillbirth, and associated factors have been studied extensively in Swedish (Phillipsson, 1976a,b,c) and in U.S. dairy cattle breeds (Pollak and Freeman, 1976). Dystocia is affected by several nongenetic factors, such as age and parity of the dam, sex of calf, year and season, size of the calf, and management intervention. Cows with shorter wither height and shorter pelvises tend to require more calving assistance. Heavier calves, winter calvings, earlier parity, and male calves were all related to an increase in dystocia rates.

Stillbirth is a substantial problem in the dairy industry, particularly at first calving. It is predominantly associated with dystocia. Cady and Burnside (1982) reported that 9.7% of approximately 29,000 calvings resulted in stillbirth. This stillbirth rate was 5.5% for animals with unassisted or easy calvings and 40.8% for those with dystocia. Because 23.6% of the heifers at first calving had dystocia, stillbirth was a major problem in this group (Cady and Burnside, 1982). Other reports have described stillbirth rates of 5.0% of calvings in 329 Pennsylvania herds (Heinrichs et al, 1987b) and 5.4% of calvings of 250,000 Israeli Holstein cattle (Weller et al, 1988). Although milk is the primary source of revenue in the dairy industry, calves provide income from direct sales and as replacements. The annual loss from stillbirth has been estimated at $5.2 million in Ontario (Cady and Burnside, 1982). This represents a $520 loss per farm annually. Strategies to reduce the stillbirth rates need to be evaluated and adapted.

In the beef cow-calf industry, attempts have been made to reduce the rates of dystocia and stillbirth prospectively by selection of heifers with larger pelvic openings as replacements for the breeding herd. In one controlled study, however, the predictive value of the pelvic area for the occurrence of dystocia in beef heifers was low (Van Donkersgoed et al, 1990). The usefulness of this technique in dairy heifers has not been reported.

In general, the heritability of calving difficulty is low (approximately 10%). If dystocia is measured as a direct effect of the sire, differences among dairy bulls have been reported (Berger and Freeman, 1978). The AI industry has evaluated Holstein sires for the tendency of their calves to have dystocia. Originally, a linear procedure was used to calculate this index, and this system is still in use in Canada. In 1988, the U.S. evaluation system was modified to a categoric method (Djemali et al, 1987a). The overall goal of these programs is to identify sires that might be preferred for mating to heifers and small cows, because less assistance is needed during the birth of the progeny of these sires.

Dystocia is not an all-or-none trait. Variations exist within sire progeny groups. Easy calving sires may have some progeny that are born with difficulty, and difficult calving sires can have some progeny that are born without assistance. Sires are evaluated for calving ease based on a standardized threshold model at Iowa State University in a program supported by the National Association of Animal Breeders. The model includes effects of herd-year, sex of calf, parity of dam, season of birth, birth-year group of sire, and sire of calf (Berger, 1994). Unlike other genetic traits that are expressed on a continuous scale of measurement, the expected progeny differences (EPD) for calving ease are in standard deviation units which are difficult to interpret, particularly when the original data are in scores of 1 to 5 (Berger, 1994). The method of reporting each sire's evaluation helps dairy producers understand the expected risk of using a sire chosen for easy or difficult calving and addresses their needs in planned matings to minimize calving difficulty of future progeny. The evaluation of each sire is reported to dairy producers as the expected percentage of difficult births (EDB) in primiparous cows. The EDB is calculated by transforming a linear function of the solutions from the threshold model to a scale of probabilities. The analysis is based on direct comparisons among sires with progeny in the same herd years. Sires in herd years without progeny of other sires in the same herd-years contribute little information to the analysis. Thus it is important to have as much information as possible from all sires in the same herd-years.

Dystocia evaluations are intended to increase the use of AI for heifers. Bulls can be selected so that the likelihood of a difficult calving is reduced. When bulls chosen for easy calving are selected for mating to heifers, this selection should follow or be within groups of bulls of comparable genetic merit for traits with higher economic value than that for dystocia. The sire evaluations for calving ease can be used to improve the economic efficiency of herd breeding programs without giving up genetic improvement for traits that are part of the selection objective.

There may be limited progeny information for young sires, and their evaluation for calving ease is subject to change as more progeny information becomes available for later evaluations. The reliability of each sire's evaluation for calving ease indicates the amount of information available to determine the predicted merit for calving ease.

Dairy producers are encouraged to select a bull with a higher reliability if the choice is between two bulls with the same EDB for calving ease.

The calving ease ratings reported for proven sires by the AI units are often underused for mating selections in replacement heifer management programs. It is essential that data concerning the difficulty of first calving be recorded. This information is integral to make a knowledgeable decision regarding the need for proactive selection. A system of scoring calving should allow for easy classification into broad categories. An example of one system is shown in Table 9-11 (Cue and Hayes, 1985). Using this system, calving ease is categorized into four groups, from unassisted or unobserved (category 1) to cesarean surgery (category 4). It is possible to adapt a numerical score to this system. The data can be recorded in any easily retrievable manual or computerized record system with the associated stillbirth information. The dystocia and stillbirth rates should be calculated and reviewed regularly.

Breeding organizations do not select bulls for calving ease, which is confirmed by the relatively constant under-

TABLE 9-11

Calving Ease Classification and Scoring System

Category	Description	Score
1	Unassisted or unobserved	100
2	Easy pull	100
3	Hard pull	50
4	Surgery	0

From Cue RI, Hayes JF: *J Dairy Sci* 68:958-962, 1985.

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weighted mean EDB. Because the weighted mean EDB is lower than the unweighted mean, bulls chosen for easy calving are used more frequently than their contemporaries with higher EDB. Therefore the opportunity to reduce calving difficulty has been an effective incentive for producers to mate more heifers to AI bulls. National in scope and international in implication, the NAAB Calving Ease Sire Evaluation program benefits AI organizations, dairy producers in North America, and dairy producers in other countries who routinely import semen, embryos, and animals.

Monitoring Reproductive Performance in Dairy Heifers

Programs for the monitoring and management of reproductive performance in lactating dairy herds have been common for many years (Williamson, 1987). However, the regular assessment of replacement heifer reproductive performance is rare, even though the general categories of information needed are the same as for the milking herd. In order to assess reproductive performance in dairy replacement heifers properly, there is a need for indexes of overall reproductive performance and for indicators of heat detection efficiency and the success of inseminations. For example, the age at first service and the age at first calving are indicators of overall reproductive performance. The age at first detected estrus and the interservice interval provide a reasonable measure of heat detection efficiency. The pregnancy rate over all services can be used to evaluate the success of insemination. Calculation of these few important indexes produces a useful assessment of replacement heifer reproductive performance.

As with many other aspects of replacement heifer health management, it may be difficult to obtain reproductive performance information on a routine basis. Many DHI record processing centers do not provide any measure of heifer performance other than age at first calving. Other centers provide a considerable amount of detail about the replacement heifer herd. The sections on maintaining record systems described in Chapter 3 are appropriate in this context. Many dairy herd management microcomputer software systems provide extensive information on individual heifers as well as averages for the replacement herd. The use of these programs on farms, or as a bureau system based in veterinary practices, has been reviewed (Lissemore, 1989). However, the usefulness of computer herd management programs for improving replacement heifer performance has not been reported. The use of these systems can take time to gain widespread acceptance, but manual record systems can be adapted easily to calculate the desired reproductive performance parameters for replacement heifers. An example of one manual system that can be adapted for heifers is shown in Chapter 3.

The optimum organization of a reproductive health management program for dairy replacement heifers is not well documented. Williamson (1987) proposed that heifers should be examined if (1) no heat is seen by 15 months of age, (2) interestrus intervals have exceeded 35 days, or (3) breeding occurred 35 days or more ago, without observed heat since. Based on the diagnoses and recommendations from rectal palpation findings of individuals in these categories, it is suggested that target reproductive performance indexes can be achieved. The size of the replacement heifer group, the seasonality of heifer management, and the availability of adequate restraint facilities determine the frequency of heifer reproductive examinations. Continual monitoring of heifer reproductive performance allows implementation of the health management cycle (Fig. 9-12).

Health and Disease Management

The future productivity of the dairy herd is largely based on its ability to replace culled animals with superior individuals. Thus a major objective of replacement management programs is to ensure that replacement animals entering the milking herd are of excellent health status and are prepared to deal with new stresses that present themselves. For example, it has been shown that there are detrimental effects of respiratory disease on survivability and on age at first calving (Correa et al, 1988). Calves with respiratory disease were twice as likely to leave the herd and to calve 6 months later than calves without respiratory disease. Based on data collected in the United Kingdom, the total cost of respiratory disease per 100 calves in a herd was $3584, which is a major cause of economic loss that must be minimized (Esslemont and Kossaibati, 1999). Calves treated for diarrhea are 2.9 times more likely to calve at 900 days of age or greater (Waltner-Toews et al, 1986b). Detailed studies that quantify milk and component production in replacement heifers of varied health status have not been reported.

The major areas of management of health in dairy heifers involve the control of parasites, coccidiosis, certain bacterial and viral diseases of the respiratory and alimentary tracts, keratoconjunctivitis, pododermatitis, and udder health management.

Parasite Control

There is considerable influence of geography and environment on the need for intensive parasite control programs (Reinemeyer, 1990). Strategic anthelmintic treatment programs are the methods of choice for replacement heifer parasite control. The major objective is to break the cycle of parasite transmission by halting the development of the parasite and by reducing the risk of infection and reinfection. This can be accomplished with sustained-release therapy (Gibbs and Kitsos, 1985) or with two strategic anthelmintic treatments at 3 and 6 weeks after turnout to pasture (Herd et al, 1987). The factors that should be considered in determining the most efficient approach to internal parasite control are the availability of labor and restraint facilities, the pasture stocking density and rotation rate, the climatic and pasture drainage conditions, and the costs of anthelmintic preparations.

The seasonal control of external parasites, such as warbles and lice, can be economically important in many dairy herds (Berkenkamp and Drummond, 1990). The use of ivermectin in the fall months has been effective in limiting the effects of these parasites and in minimizing the need for more extensive control programs. However, in some herds, the control of lice throughout the winter may require the implementation of additional measures, such as the use of pour-on organophosphate preparations.

Coccidiosis is a self-limiting disease and control can be achieved through the development of immunity (Schillhorn van Veen, 1986; Ernst and Benz, 1986). However, the effects of transient, naturally occurring coccidial infection on growth, reproductive performance, and future productivity have not been defined. It is difficult to relate the prevalence of infection with coccidiosis or the proportion of cases with clinical disease to replacement heifer performance. It has been suggested that clinical signs, severity, and losses resulting from coccidiosis are variable and are often related to stress factors such as weather, weaning, and crowding (Schillhorn van Veen, 1986). Several compounds can be fed to calves to control or reduce the severity of the coccidiosis, including lasalocid (Bovatec, Hoffmann-LaRoche) and decoquinate (Deccox, Rhne-Poulenc-Rorer).

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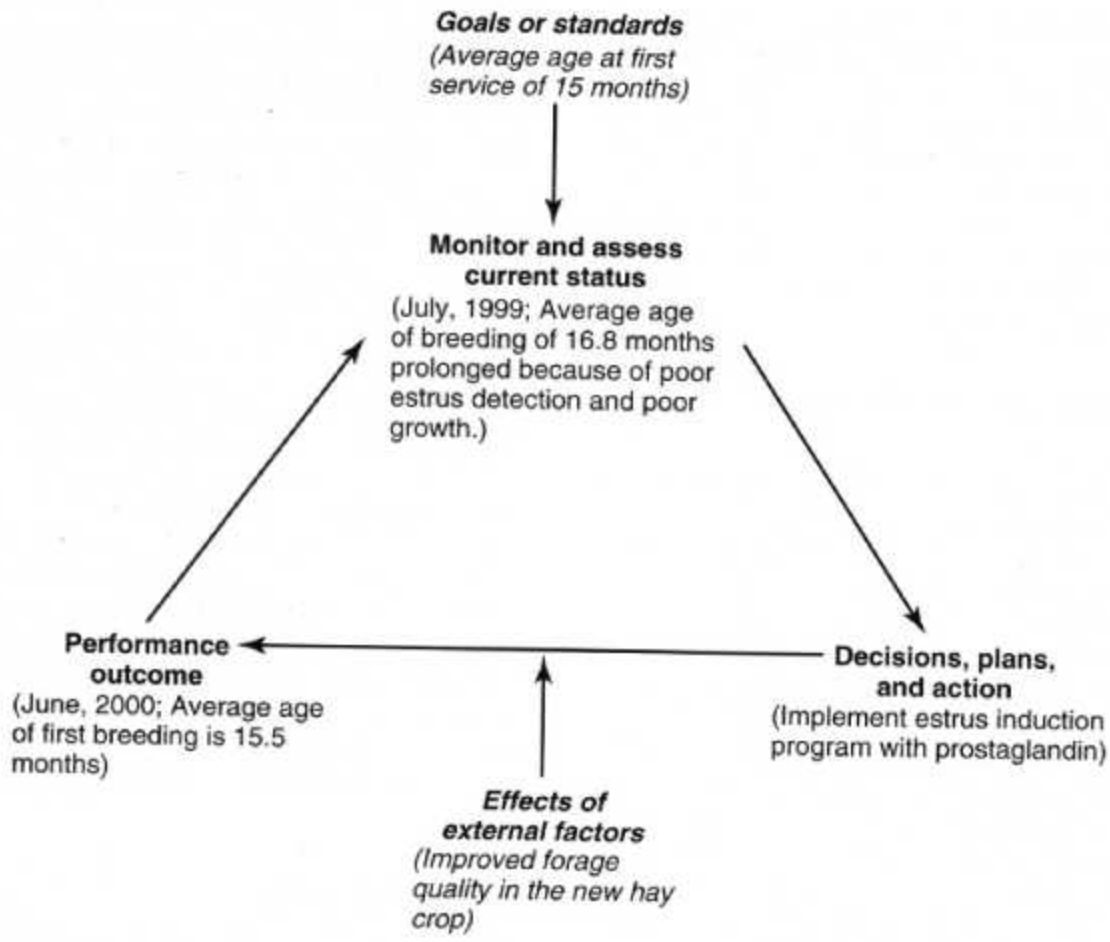

FIG. 9-12 Using the health management cycle in a heifer reproductive program. The herd has age monitored at first breeding and is above the target level. A prostaglandin estrus induction program is implemented. Over the next 11 months, average age at first breeding has improved. Improved nutrition resulting from higher quality forage may have been an important factor in the performance outcome. Monitoring is to continue, and new plans can be formulated.

Although some studies have demonstrated improved weight gains in experimentally infected calves (Conlogue et al, 1984), there is concern about the similarity between experimental infection and natural exposure. The pattern of oocyst shedding, in the absence of clinical signs, may provide little indication as to the need for medication or the prediction of long-term effects of the disease. One study found that lasalocid and decoquinate were effective in reducing coccidia in young calves under conditions of low naturally occurring exposure and good management (Hoblet et al, 1989). These findings were the same as in other studies after experimental inoculation (Foreyt et al, 1986; Stromberg et al, 1982) in that reductions in oocyst shedding were not accompanied by a significant improvement in weight gain. Subjective evaluations of medicated calves reported glossier hair coats and healthier appearance than nonmedicated controls. Perhaps these visual changes are responsible for the widespread inclusion of decoquinate in commercial calf starters in some regions, such as Ontario (Rodenburg, 1989). For recently weaned calves, estimated costs are 2 to 3 cents/head/day. Waltner-Toews et al (1986a) have reported that over 80% of Ontario producers start feeding calf starter grains at less than 2 weeks of age and that over 60% use commercial preparations. The cost-effectiveness of this use of coccidiostats for improved performance in dairy replacement programs needs further study.

Replacement heifers reared on pastures are commonly affected with gastrointestinal parasites. Continuous ivermectin treatment from birth to puberty in dairy heifers grown on nematode-infested pastures can increase growth rate, advance the onset of ovarian activity, and positively affect yearling pelvic area (Mejia et al, 1999).

Infectious Disease Control: Vaccines and Immunization Schedules

The principles of the control of infectious diseases are presented in Chapter 4. A health management program for dairy replacement heifers must emphasize the reduction of the degree of exposure to infectious agents. Appropriate nutrition and attention to the genetic aspects of disease resistance are important for immunocompetence and the prevention of infectious disease. However, a replacement heifer health management program offers the ideal opportunity to immunize heifers selectively against the major infectious agents.

A wide range of bacterial and viral vaccines is available in North America against the major infectious diseases of dairy cattle. Most vaccines are multivalent preparations containing inactivated or live antigens (Bowland and Shewen, 2000). The selection of the specific diseases against which dairy replacement heifers are vaccinated depends on several factors. The risk of exposure to a particular disease, the efficacy of the available vaccines, and the costs involved in carrying out a recommended program are important variables (Radostits and Tremblay, 1994). In addition, the regulatory requirements in each particular region and the restrictions imposed by the domestic or foreign markets targeted by the herd for sale of surplus heifers are other important points to consider. An immunization program for dairy replacement heifers in North America includes the use of vaccines against IBR, parainfluenza-3, bovine virus diarrhea, BRSV, and a bacterin containing five strains of *Leptospira* sp. Vaccination of dairy heifers against BRSV before parturition—twice at 2-week intervals, with the second vaccine administered at 2 to 3 weeks before calving—may increase milk production and first insemination conception rates (Ferguson et al, 1997).

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The need for vaccination against *Brucella abortus,* rabies virus, and clostridial agents depends on the region and characteristics of the individual farm.

To be effective, a vaccination program must be planned according to the age of heifer and season of the year. The strategy is to induce protective immunity as early as possible after the decline of maternal antibody levels. Revaccination before breeding age serves to maximize protection during the vulnerable stages of pregnancy against some of the major pathogens. One approach that meets these outlined objectives and criteria is to organize an annual immunization program for replacement heifers on a quarterly basis. Heifers are vaccinated between 5 and 8 months of age, and revaccinated 6 months later between 11 and 14 months of age, to booster immunity before breeding. This schedule ensures that all heifers are vaccinated twice before first lactation and before becoming part of the health management program for the milking herd. The seasonal risk for some problems, suchs as leptospirosis, may dictate early fal vaccination for this disease.

The recommended vaccination schedule for dairy heifer replacements is shown in Box 9-3.

The final components and organization of a replacement heifer vaccination program for a specific farm are derived after consultation and deliberation regarding the risks of disease, efficacy of available vaccines, and specific economic factors important on that farm. A high percentage of dairy herds are not adequately vaccinated against bovine virus diarrhea (Rauff et al, 1996), and veterinarians are not taking full advantage of their pivotal role in dairy vaccination and herd biosecurity programs. According to the National Dairy Heifer Evaluation Project of 1991-1992, in the United States, only 33% to 46% of dairy cattle producers vaccinated dairy heifers between weaning and first breeding for IBR, bovine viral diarrhea, BRSV, and parainfluenza-3 virus. From 32% to 44% of producers vaccinated for those diseases between breeding and calving. Only 19% vaccinate for clostridial diseases, whereas 65% vaccinated for brucellosis. In a survey of dairy herds in Saskatchewan only 25% of dairy producers appear to follow the label directions for administering killed virus vaccines (Carruthers and Petrie, 1996).

BOX 9-3

Recommended Vaccination Schedule for Dairy Heifer Replacements

CALVES AT 6 TO 8 MONTHS OF AGE
Clostridial bacterin (eight-way antigen)
Infectious bovine rhinotracheitis-parainfluenza-3
Bovine virus diarrhea
Bovine respiratory syncytial virus
Leptospira pentavalent

HEIFER REPLACEMENTS AT 13 TO 15 MONTHS OF AGE (AT LEAST 3 WEEKS BEFORE BREEDING)
Infectious bovine rhinotracheitis-parainfluenza-3
Bovine virus diarrhea
Leptospira pentavalent

Udder Health in Replacement Heifers

Several studies have reported the prevalence of intramammary infections in nulliparous dairy replacement heifers (Bray et al, 1989; Oliver and Mitchel, 1983; Trinidad et al, 1989; White et al, 1989). Although there is considerable variability in the reported infection rates, mastitis is undoubtedly more frequent than would be expected in heifers before entering the lactating herd. The majority of these infections are caused by coagulase-negative *Staphylococcus* sp. Bacteria, which are eliminated spontaneously or with antibiotic therapy during early lactation (Myllys, 1995). However, high rates of *Staphylococcus aureus* have also been reported in bred heifers (Trinidad et al, 1989). In this particular situation, with such a high prevalence of an important intramammary pathogen, it was shown that antibiotic therapy of heifers before their first parturition had a beneficial effect by reducing the prevalence of infection and by increasing first-lactation milk production (Trinidad et al, 1990). Another study, with lower prevalence of *S. aureus* infection, did not confirm this improvement (Bray et al, 1989). Prepartum intramammary therapy of primigravida heifers with commercial dry cow antibiotics (penicillin-novobiocin or cephapirin) caused cure rates of 94% to 100% for *S. aureus* (Owens and Ray, 1996). Recommendations concerning the maintenance of udder health status in replacement heifers require information on the prevalence of infection and the types of organisms involved.

Mastitis in heifers can occur in well managed, productive herds with low somatic cell counts and a high frequency of mastitis treatments administered by the veterinarian (Myllys and Rautala, 1995). Recovery from clinical mastitis is good, but mastitis in heifers is a cause of culling.

The sources of intramammary infection of heifers with *S. aureus* at parturition are milk from other infected mammary glands and heifer body sites (Roberson et al, 1998). Contact among heifers may be an important mode of transmission of *S. aureus,* leading to intramammary infection in heifers at parturition. Horn flies (*Haematobia irritans*) are able to transmit *S. aureus*-induced intramammary infection to heifers, and scabs on teats are a potential source of the organism (Owens et al, 1998). Fly control on dairy cows in herds with known *S. aureus* mastitis problems is recommended as a method to control infection.

Elective Procedures

Dehorning and removal of supernumerary teats are most easily done before weaning but should be completed by at least 4 and 8 months of age, respectively. During the growing period, heifers should be examined to confirm that these procedures have been completed appropriately. The removal of the medial dewclaws of young calves for the prevention of teat injuries in later life as stabled lactating cattle was recommended for many years, but there has been no evidence from formal field trials or observational studies that this procedure is necessary. Reticular magnets can be administered at 15 months of age or at the time of first breeding for the control of traumatic reticuloperitonitis. This recommendation depends on the occurrence of potential risk factors for this condition in the population in question.

Biosecurity in Dairy Heifer Replacements

Several diseases of cattle may be introduced into dairy herds by the importation of heifer replacements that may be infected unknowingly with pathogens. These include enzootic bovine leukosis, Johne's disease, bovine virus diarrhea, brucellosis, *N. caninum,* papillomatous digital dermatitis, and contagious mastitis pathogens. Serological tests can be done for enzootic bovine leukosis, Johne's disease, and brucellosis. Blood can be cultured to detect animals persistently infected

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with the bovine virus diarrhea virus. Imported animals should be tested and found to be seronegative before entry into the herd or kept in quarantine in the herd of entry until the test results are available. A high percentage of dairy herds with digital dermatitis could be prevented using management strategies related to biosecurity (Wells et al, 1999). Congenitally acquired *N. caninum* infection in calves can cause a substantial number of abortions during the initial pregnancy of heifers, and subsequent abortions can be expected in congenitally infected cows that have aborted previously (Thurmond and Hietala, 1997). Seropositive heifers commonly give birth to calves with high *Neospora* titers, and congenitally acquired *Neospora* sp. infections can persist in healthy heifers and can be transmitted transplacentally to the next generation (Anderson et al, 1997). Thus seropositive heifers should be culled, but there is no assurance that all seronegative animals are free of infection. Feed biosecurity and water contamination are also considerations in preventing the introduction of pathogens into dairy herds. Animal by-products such as meat and bone meal may be contaminated with salmonella, which may be introduced into a dairy herd (Bender et al, 1997).

Monitoring Disease Control in Replacement Heifers

The efficiency of disease control programs in dairy replacement heifers can be monitored by calculating morbidity and mortality rates, in addition to charting growth. Disease-specific morbidity rates for conditions such as pneumonia or abortion are useful to assess the efficacy of vaccination programs. Care must be taken to ensure that the appropriate numerator and denominator are used in the calculations, as described earlier. With the determination of such rates and with the measurement of growth, it is possible to complete the health management cycle for disease control. An example of this process is depicted in Fig. 9-13.

Details of a monitoring system for replacement heifer rearing are available (Quigley et al, 1996). The headings of a calf-rearing chart, which can be customized to meet the needs of individual farms, are shown in Box 9-4 (Quigley et al, 1996).

Genetic Selection and Numbers of Replacements

The replacement heifer herd is the major source of additions to the milking herd. Thus it is important that the number of heifers available and their genetic potential be greater than the potential and number of cows being removed from the herd (Rodenburg, 1989). To ensure that this potential for progress is realized, several requirements of a replacement heifer management program should be met (Box 9-5).

Artificial Insemination of Replacement Heifers

A survey in Pennsylvania found that only 59.5% of herds used exclusively AI breeding programs for their replacement heifers (Heinrichs et al, 1987b). The use of AI offers the availability of sires with proven genetic merit. Selection can be based on the maximum genetic improvement in desired production and conformation traits while being cognizant of calving ease.

The use of a beef breed bull on dairy replacement heifers in an attempt to reduce dystocia rates is common. This practice, however, is neither without risk of dystocia or venereal disease, nor a substitute for better replacement management to raise well-grown heifers. In addition, a large number of potential replacement heifers are not produced. Assuming that animals of different parity have equal probabilities of having a heifer calf and of calf survivability, first-calf heifers produce approximately 30% of the heifers born, as compared with 25% and 20% from second-lactation and third-lactation cows, respectively.

The use of an AI breeding program in replacement heifers offers several other advantages over natural service. The

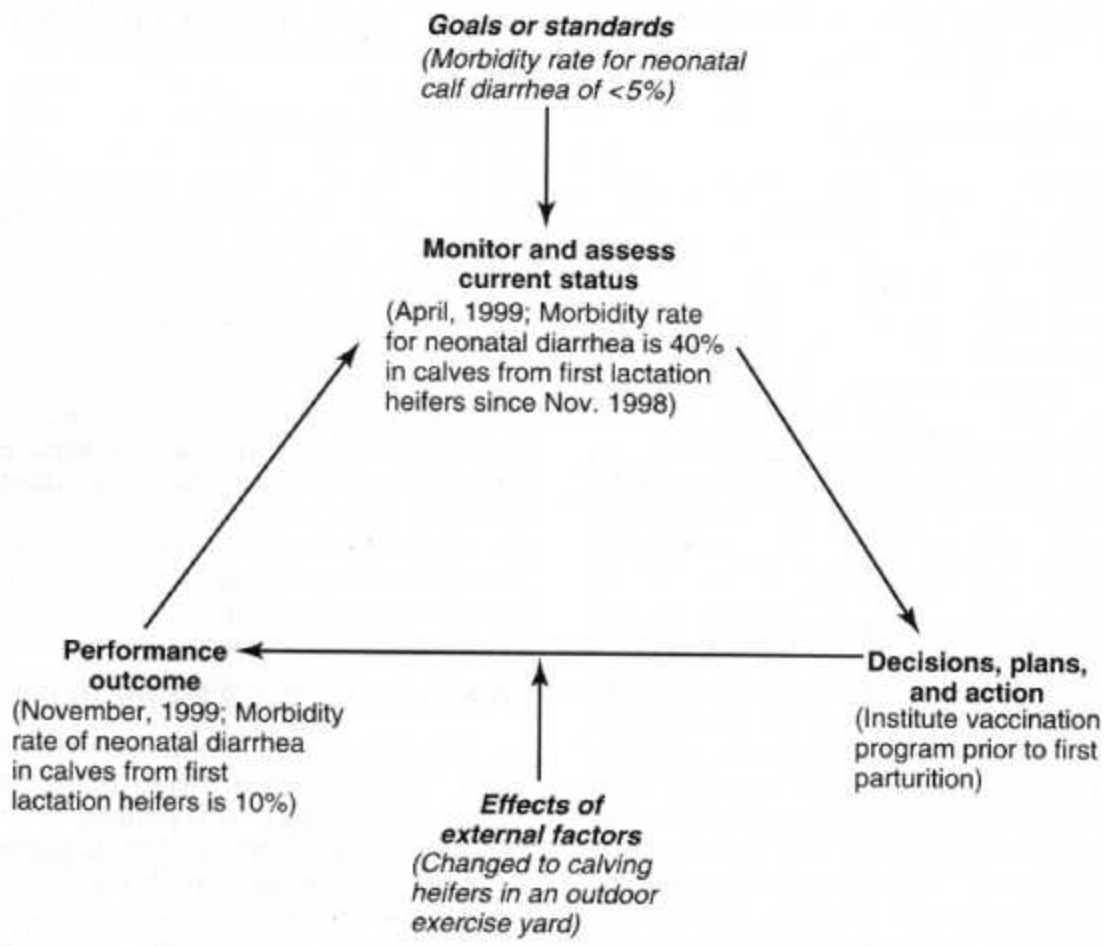

FIG. 9-13 Using the health management cycle in a replacement heifer disease control program.

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record keeping necessary for an AI program benefits animal identification and observation. The facilities required for an AI program, such as smaller group sizes and self-locking head gates, enhance the ability to deliver better nutritional management. An AI program offers more opportunity to restrict the times when heifers calve, if this is a management advantage.

In summary, the use of AI in dairy replacement heifers can lead to excellent reproductive performance and offers the greatest potential for genetic progress within a herd.

BOX 9-4

Headings of a Calf Rearing Chart

I. Identification of the calf
II. Date of birth
III. Birth weight
IV. Date of arrival, if purchased
V. Clinical diseases, treatments, and dates
VI. Vaccinations and dates
VII. Prophylactics administered and dates (anthelmintics, magnets)
VIII. Weaning date
IX. Heart girth and weight measurements and dates
X. Intended mating sire
XI. Estrus dates
XII. Insemination dates
XIII. Positive pregnancy diagnosis
XIV. Date and reason of culling
XV. Comments

Monitoring Genetic Progress

The accurate identification of heifer calves is essential to ensure genetic progress. Advances in electronic animal identification can assist with this aspect in the future. The reproductive and health records are also helpful in making decisions about the replacement potential and mating selections of individual heifers. An estimate of the genetic merit can be calculated for all replacement heifers with known parentage. The details of genetic indexes are discussed in Chapter 7. Animals with inferior performance potential can be removed preferentially.

Herd Reproductive Performance

Poor reproductive performance adversely affects the opportunities for selection from replacement heifers. The potential number of calves available declines as the calving interval increases. The effects of herd calving interval on the number of replacement heifers available (Table 9-12). As the calving interval increases by 1 month, approximately 8% fewer calves are born each year. Thus a herd with a 14-month calving interval has 84 calvings per 100 cows annually. Reasonable assumptions are that 50% of calves are females and that 25% of heifer calves leave the herd before 24 months of age because of various factors, ranging from illness and poor growth rate to infertility as a yearling heifer. With these assumptions, an increase in the calving interval from 12 to 15 months can decrease the number of heifers available for selection, because replacements decrease from 38 to 29 heifers per 100 cows annually. Age at first calving also affects the number of heifers available for selection as replacements. The effect of an increase in age at first calving on the inventory of replacement heifers needed as herd replacements at various culling rate levels, assuming a 10% heifer culling rate, is summarized in Table 9-3. A herd of 100 dairy

BOX 9-5

Requirements of a Replacement Heifer Management Program

Sires of superior genetic merit should be used on heifers through artificial insemination.
Genetic progress in the replacement herd should be monitored through accurate animal identification, detailed record systems, and accessing predicted genetic indices for the replacement herd.
The reproductive performance of the herd must be maintained, because it directly affects the number of replacement heifers available.
The losses of calves and heifers must be minimal to enhance the number of quality replacements available.

TABLE 9-12

Effect of Herd Calving Interval on Replacement Heifers Produced Annually

Calving Interval (mo)	Average Calves Born Annually (per 100 Cows)	Bred Heifers Available (per year)*
12	100	38
13	92	35
14	84	32
15	76	29

*Assumes that 50% of calves born are females and that 75% of female calves survive and are available to freshen as first-calf heifers.

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cows with a 24% culling rate needs an inventory of 54 heifers of all ages if a 24-month age at first calving is maintained, compared with an inventory of 62 heifers if age at first calving is 28 months.

In summary, the herd reproductive performance and the age of first calving directly affect the number of heifers available as herd replacements. In turn, the ability to apply some selection pressure on both milking cows with a poor record of performance and on heifers with poor genetic potential to produce relies on having an abundant supply of replacement heifers.

Successful replacement heifer raising programs have lower death losses and provide a greater opportunity to cull cows and heifers with less genetic potential. If calf morbidity and mortality have been high, it is possible that the entire remaining group of replacements is needed. Genetic gain is limited because of the necessity to keep inferior cows and replacements in the herd. It is desirable to have a sufficient replacement inventory to allow for a 10% culling rate among heifers.

Under grazing conditions in New Zealand, it is suggested that dairy heifers should reach 60% mature weight by 15 months of age for optimum fertility at first breeding, and 90% mature weight by 22 months for optimum milk solids production in the first lactation (Penno et al, 1997).

ECONOMICS OF REPLACEMENT HEIFER HEALTH MANAGEMENT

The investment in raising replacement heifers is the second largest financial input into a dairy enterprise (Donovan and Braun, 1987; Goodger et al, 1989). Feed costs for the lactating herd represent the largest dollar input. However, raising dairy replacement heifers can account for 15% to 20% of total dairy enterprise costs (Annexstad, 1986). Some of the costs associated with raising replacement heifers have been studied extensively. Estimates of the costs to raise a calf to 24 months of age range from $1080 to $1353 (U.S. dollars) (Annexstad, 1986). These estimates probably included major differences in management, environmental conditions, housing needs, feed sources, measurement of weight gain, and general market conditions at the time of the study. Any change in feed, labor, and energy inputs would dramatically affect the cost estimates.

Age at calving and herd turnover or cull rates are two of the largest factors affecting herd replacement costs as it affects the numbers of heifers that must be raised to maintain herd numbers. When age at calving increases, so does the need for heifer housing, feed, and labor. This increase can be as much as 50% or more in extreme situations. An example of this magnitude of increase would be comparing a farm with a 26% herd turnover and 22-month calving age with another having a 38% herd turnover and a 30-month age at calving. The first farm needs 53 heifers in the replacement herd while the second requires 106, or twice as many heifers just to maintain a constant 100-cow herd size. The costs to raise the extra heifers can be tremendous and make a major difference on the profit potential of each farm.

It is important for farmers to understand the overall costs involved in raising dairy heifers for both farms wanting to raise their own heifers and for those seeking contract growers. In either case, in order to do a better job or to let someone else raise them, veterinarians must know the current costs in order to do better in the future.

Heifer-raising costs are generally separated into two major categories. *Fixed costs* include buildings, equipment, property, machinery, depreciation, interest on investment, repairs, taxes, and insurance. Some of these costs are of the type that are often overlooked by those not accustomed to a rigid accounting system, but they are all real and can add a significant portion to the cost of raising a heifer. *Variable costs* include feed, labor, bedding, utilities, veterinary care, breeding, and supplies. These vary nearly proportional to the number of heifers raised at one time. Most variable costs are easily understood and calculated. Fixed costs are often hard to calculate and easy to overlook for the heifer enterprise on the dairy farm (Table 9-13).

With the current state of dairy replacement programs, the greatest immediate potential for economic improvement is in the reduction in age at first calving. Reduction in the age at first calving, to a goal of 24 months of age, would reduce the total nonproductive days and allow for a one-time surplus in replacement heifers. A spreadsheet program has been developed to calculate the losses caused by a delay in age at first calving (Fetrow et al, 1987). An example of a printout from this program is shown in Table 9-14. By reducing the average age at first calving of the 45 replacement heifers that calve each year in this sample herd from 28.3 months to a goal of 24 months, over $12,000 in input costs could be avoided. In addition, a one-time income of over $19,000 is available from the sale of 16 extra heifers. Because the age at first calving has shown little improvement in the last two decades (Powell, 1985), this type of spreadsheet could be useful as an extension tool to discuss the benefits of health management programs for improving age at first calving with producers.

Raising Heifer Replacements by Contract

A nationwide interest in raising dairy heifer replacements by contract is growing. On farms where facilities, labor, feed,

TABLE 9-13

Dairy Heifer Replacement Rearing Budget Summary

Cost Summary	Age Interval (mo)			
	0-3	3-12	12-24	0-24
Feed costs	$45. 26	$143.20	$328.56	$516.56
Total variable costs	$73.27	$197.65	$434.28	$705.20
Total fixed costs	$33.69	$91.88	$124.75	$250.31
Average cost/mo	$77.32	$37.17	$50.75	$48.98
Average cost/day	$2.54	$1.22	$1.67	$1.61

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management, or any number of circumstances are limited, contracting with someone else to raise the heifers for all or part of the growing period up to calving can make sense. Contracting heifers offers a number of advantages for the dairy farmer and may be a logical alternative to traditional methods of raising heifers. Since replacement raising costs typically account for 15% to 20% of total milk production cost, selecting the most beneficial and commercial method of raising heifers is a major one.

The National Dairy Heifer Evaluation Project conducted from 1991 to 1992 found that 1.7% of U.S. farmers have someone else raise their heifers on a contractual basis (Heinrichs et al, 1994). In the Northeast 2.4% of farmers contract their heifers to another heifer raiser. Similarly 2.1% of farmers in the Southeast contract heifers. Contract raising is less often used in the Midwest (0.5%); however it is quite common in the West (7.8%). It is likely that the numbers are growing each year as farms become larger and more specialized. Interest in this area is definitely growing. The National Dairy Heifer Project did show that herds that use contract raising are generally much larger than average (more than 230 cows) and that this trend is increasing also. This study showed that 41% of producers who use contract raising send calves out between 12 hours and 4 months of age, 47% send heifers out between 4 months and breeding, and a smaller number (12%) contract out heifers from breeding to precalving time only. A large percentage of heifers are contracted out until 2 to 6 weeks before calving, regardless of age when they were first sent to the contract grower.

Changing the way a dairy farmer allocates farm resources is the largest benefit of contract heifers. As a result of someone else raising heifers, dairy farmers should free up a variety of limited resources such as labor, management time, buildings, equipment, land, and operating capital. In addition to freeing up homegrown forages or grain for use by animals other than heifers can be considered a good reason to look at contract raising heifers. It is important that the farm use these limited resources for something more profitable once the heifers are no longer being raised at home. In addition, the alternative use of resources, in terms of profitability, must be equal or better than their use in raising heifers. If this is not the case, then one of the major benefits attributed to contract raising will be lost.

In situations in which a major farm expansion is being considered, the alternative of adding milking cows to use the resources previously occupied by the heifers may be advantageous. Eliminating the heifer-raising enterprise on the farm should allow labor and management to specialize on the milking herd. The possibility exists that the lactating herd performance could improve because of this specialization, whether or not the actual herd numbers grow. In a sense, removing the heifers from a farm operation and adding milking cows can lead to an improved cash flow for either a limited or long-term period.

Once the decision has been made to not raise heifers in a traditional manner, contract raising heifers could be considered much better than buying heifers on the open market. The herd genetics, breeding, and, most importantly, herd health programs can be controlled by the dairy farmers using contract raising. A final point is that if the farmer's actual cost of raising heifers is greater than the alternative of contracting, then the economic benefits will be important. The effectiveness of specializing in heifer raising can often result in reduced costs and perhaps better grown, healthy heifers. Contract raising heifers can provide a full- or perhaps part-time employment for someone who does not want to milk cows or whose milking facilities are not adequate to milk cows. For smaller sized operations it can provide a part-time income that has flexible hours for the part-time farmer.

TABLE 9-14

Sample Printout From a Spreadsheet Program to Calculate Losses Resulting From Delay in Age at First Calving

Parameter	Goals	Actual	Average Parameter	Costs	
				Goals	Actual
Age at calving (mo)	24	28.3	Average heifer feed/mo	$35	$38
Weight at weaning (lb)	150	150	Overhead/mo	$540	$540
Age at weaning (mo)	2	2	Overhead/head/mo	$12	$12
Weight at calving (lb)	1200	1164	Total cost/heifer/day	$1.55	$1.63
Rate of gain (lb/day)	1.59	1.29			

Price of springing heifer	$1,200
Number of heifers calving/year	45

Analysis: loss avoidable per head	Feed: $221	Total loss avoidable per year: $12,278
	Overhead: $52	
	Total per head: $273	

Income available from transition to goal by selling 16 extra heifers because of calve: $19,350

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The facilities to be used for the heifer raising, including the ventilation, water system, and grouping systems, must be sufficient to be used for heifers. Contract raising heifers allows the full- or part-time replacement grower to feed available grain and forages. Again, these must be adequate in quality, or one of the benefits of contract raising heifers is lost. One common problem is that facilities, feeds, or management not sufficient for milking cows is often not of sufficient quality to raise heifers.

Contracts for heifers may contain an option-to-purchase (owner sells the calf but reserves the right to buy the resulting spring at market price), or they may be limited to a direct contract (the dairy farmer retains ownership and pay the grower a fee). Contracts should be drawn up to protect both the heifer owner and the heifer grower. Some items to consider are the length of the contract term, a provision for termination, and a method of arbitration. A renewal clause should be negotiated after the heifers raisers' abilities have been evaluated thoroughly and one or more groups of heifers have been raised. Health requirements such as calf-hood vaccinations need to be taken care of as well as how death losses are handled and who assumes the necessary veterinary costs. The person who assumes the responsibility for breeding the heifers and paying the cost of breeding must be determined. The responsibility for transportation to and from the heifer grower must also be decided.

Contracts drawn on a year-to-year basis provide flexibility in establishing fees and other cost figures that parallel the general farm economy. Contracts should be written to permit the addition and deletion of animals as conditions dictate. The method of payment should also be determined in the contract. Monthly charges, fees based on body weight gain, or a one-time fee similar to purchasing are often the options.

Accounting records and animal identification are absolutely important for contract raising. These will aid both the owner and grower. Both the owner and the grower should retain copies of all records. In addition, preestablishing performance guidelines are absolutely necessary. Heifer owners may wish to dictate ration components and dry matter intakes or may want to establish minimum and maximum guideline on growth, both weight and height at a given age. If growth is an established criterion for assessing a benchmark of performance or establishing a fee structure, height at withers or some other measure of skeletal structure should be used in addition to body weight. Ranges of acceptable growth should be used to account for individual and genetic variation between animals. In addition, the subjectivity of body condition scoring of heifers may not make it the best alternative for monitoring performance.

Costs of raising heifers may be dictated by the age that heifers are received. Labor and feed costs of very young calves may be much higher per day than for older heifers. The contract raiser must determine these costs in relation to the time period that they will have the heifer in order to determine the appropriate charges to make. Since the objective and resources are so different from farm to farm, an analysis of benefits and active cost must be calculated on a farm-by-farm basis.

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CHAPTER 10

Mastitis Control in Dairy Herds

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The production of high-quality milk is a realistic and meaningful goal for all aspects of the dairy industry and the primary motivator for establishing a mastitis control program in a dairy herd. The thrust of these efforts has been the implementation and use of management techniques to limit the spread of major mastitis pathogens, thereby reducing the quarter infection rate. Detailed mastitis control strategies have been outlined and promoted by the National Institute for Research in Dairying (NIRD) and by the National Mastitis Council (NMC). With proper implementation, these programs cause a dramatic decrease in the prevalence of common contagious mastitis pathogens (Jackson, 1980; Dodd, 1983; Smith, 1983). Herds that have successfully implemented a comprehensive mastitis control program also need to develop strategies to control infection with environmental organisms and need to use an effective monitoring system for new infections (Smith et al, 1985b). However, the adoption of effective mastitis control programs has often been less than desirable (Gill et al, 1990; Godkin, 1990; Hueston, 1987), despite extensive research validation of the recommended control practices and major extension efforts at both national and local levels. The reasons for this slow adoption of mastitis control strategies have not been documented. Research in Minnesota has shown that producers look to the veterinary profession for information on mastitis and its control (Burton et al, 1988). If significant progress is to be made toward a general improvement in udder health status, veterinarians must remain active in organizing, conducting, and monitoring comprehensive mastitis control programs. Box 10-1 lists the 10 fundamental elements of a mastitis control program as recommended by the NMC. Emphasis and details of each point may vary from herd to herd; however, if practiced with consistency, mastitis should be minimized as an economic loss for a dairy.

DEFINITIONS AND TERMINOLOGY

Mastitis is an inflammation of the mammary gland and primarily results from invasion of pathogenic microorganisms through the teat canal. An *intramammary infection (IMI)* has occurred if the invading pathogen causes an inflammatory response and loss of potential milk production in the affected quarter of the gland. Mastitis can occur with a wide range of clinical signs, from subclinical to severe, which is dependent on the virulence of the pathogen and the extent of the response of the host immune system. *Subclinical mastitis* is defined as the presence of pathogenic organisms in the milk, and an inflammatory response that can only be detected by screening tests or laboratory procedures. Thus signs of inflammation that are detected by visual observation or palpation such as swelling, heat, redness, pain, or systemic responses such as fever, are not observed. The causative agent(s) can only be identified reliably from bacteriologic culture of milk. *Somatic cell counts (SCCs)* of milk, which are essentially measurements of the concentration of leukocytes in the gland, are the most frequently employed method to detect inflammation. The correlation between IMI and elevation of SCCs is not perfect, but it is a very strong relationship in predicting both infection status of individual cows and prevalence of chronic IMI in a herd. More than one quarter may be infected simultaneously, which also tends to increase composite (commingled samples from all four quarters) SCC. Cows with a linear SCC less than 4 ($\leq$141,000 cells/ml) are usually not infected. Likewise, bulk tank SCCs below 150,000 cells/ml are usually associated with a low prevalence of IMI in a herd.

Clinical mastitis results when the cow's immune system responds with enough intensity to an IMI to elicit signs of inflammation that are physically observable. The nearly universal observation of clinical mastitis is abnormal color or texture of milk. As the degree of local inflammation increases, swelling, discoloration, and pain in the udder may become evident. Typically, clinical manifestations of the inflammatory response are seen in only one quarter at a time, although multiple quarters can exhibit clinical signs, especially for *Mycoplasma bovis*. In mild clinical mastitis, clinical signs are generally restricted to local involvement of the udder. In severe clinical mastitis, systemic involvement is apparent, with varying responses such as fever, anorexia, depression, shock, and recumbency. Especially in the severe form, milk production can be decreased profoundly, the affected quarter may become agalactic, eventual culling may be needed, or in a small proportion of cases, death may result.

IMIs can be described as *chronic* if the duration of infection, with or without clinical signs, is greater than 2 months. Likewise, clinical cases can be described as chronic if affected quarters either frequently recur with clinical signs after apparent cures or frequently maintain a clinically abnormal status for extended periods of time. *Acute* mastitis generally refers to clinical mastitis cases, and more properly describes the rapid onset of clinical signs rather than the severity. Superimposed on this terminology are the categories of *contagious* and *environmental* mastitis. These refer to the reservoirs of particular bacterial infections. Contagious mastitis occurs with organisms that spread from cow to cow. Environmental infections occur from ubiquitous organisms commonly found in the housing environment. In studies of the herd prevalence of microorganisms in milk, two of the most common bacteria isolated are *Corynebacterium bovis* and coagulase-negative *Staphylococcus* sp. These organisms are occasionally associated with clinical changes and often induce only a moderate SCC response (Brooks et al, 1982; Erskine et al, 1987b). There is considerable debate as to the significance of these organisms for the mammary gland and for cow productivity. For this reason, these organisms are classified as *minor pathogens*. Minor pathogens have been credited

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BOX 10-1

Ten Guidelines for a Mastitis Control Program

1. Establish goals for udder health
2. Use proper milking procedures
3. Maintain a clean and comfortable environment for cows
4. Properly maintain and use milking equipment
5. Use appropriate treatment of clinical mastitis during lactation
6. Provide effective dry cow management
7. Maintain biosecurity for contagious pathogens and cull chronically infected cows
8. Keep good records
9. Regularly monitor udder health status
10. Periodically review the mastitis control program

with maintaining a higher than normal SCC and with increasing the resistance of the colonized quarter to invasion by a major pathogen (Rainard and Poutrel, 1988). There is evidence that long-term intensive programs of teat dipping and dry cow therapy can markedly reduce the prevalence of *C. bovis*, however, responses with the staphylococci are more variable.

It is necessary to be able to communicate the extent of a mastitis problem in a herd to a dairy producer. Most importantly, a *case definition* of a mastitis case must be used, particularly for clinical mastitis cases. Once a clinical case or IMI has been defined, it is then possible to determine the extent of the problem. The *prevalence* of mastitis in a herd is defined as the number of cows (or quarters) that are diagnosed as infected divided by the total number of cows (or quarters) currently at risk of infection. Prevalence yields a proportion of the herd that is infected at one point in time. Bacteriologic culture of milk samples collected from a herd is the preferred method to determine the prevalence of infection. Interpretation of the calculated prevalence of mastitis depends on three important factors: (1) the incidence of new intramammary infections, (2) the duration of intramammary infections after they have occurred, and (3) the rate that infections are removed from the herd by treatment, spontaneous cure, culling, or death.

Determination of prevalence can offer reliable insight for contagious pathogens such as *Streptococcus agalactiae* and *Staphylococcus aureus*. Herd bacteriologic cultures are sensitive and specific indicators of IMI caused by these and other organisms that have a long duration and relatively low rate of spontaneous cure. The magnitude of infection caused by coliform (lactose fermenting, gram-negative rods of the family Enterobacteriaceae) organisms is often poorly described by herd culture of cows at one point in time, because infections are more transient and most IMI spontaneously cure in less than 30 days. In addition, clinical signs of mastitis that develop as a consequence of coliform IMI usually persist for less than 7 days. Thus routine culture of suspect cows with high SCC following monthly testing by Dairy Herd Improvement (DHI) organizations would be timed poorly to identify the dynamics of clinical mastitis in a dairy herd if a high proportion of the causative agents are coliforms.

Prevalence studies of IMI in dairy herds have been reported (Brooks, 1982; Gonzalez et al, 1988; Erskine et al, 1987b). A review of this information requires particular attention to the method used to select study herds, the criteria for inclusion in the study, the sampling methodology used, and the techniques used for bacteriologic culture. There are undoubtedly broad variations among different countries, regions, and individual herds for the prevalence of contagious pathogens. Numerous studies have identified that herds with low SCC have low prevalence of IMI caused by contagious pathogens (Eberhart et al, 1982; Hogan et al, 1989b; Schukken et al, 1989a; Erskine et al, 1987b). In a Pennsylvania study (Erskine et al, 1987b) the herd management characteristics and prevalence of mastitis in a group of dairy herds with a high mean herd SCC (>700,000 cells/ml) was compared with a group of herds with a low mean SCC (<150,000 cells/ml). In the low SCC group, 0.2% of the cows were infected with *Str. agalactiae* compared with 50.9% in the high SCC group. Similarly, the *S. aureus* prevalence was 1.8% versus 22.2% in the low and high SCC herds, respectively. It was clear from this study that implementation of the NMC-recommended mastitis control practices drastically reduced prevalence of the major contagious mastitis pathogens. The prevalence data for minor pathogens, such as *C. bovis* and *Staphylococcus* sp., vary among herds, but a high proportion of cows may be infected with staphylococci even in herds with relatively low SCC.

The mastitis *incidence* is the number of new cases of IMI or clinical mastitis in the population at risk during a given period. Mastitis incidence relates to how much the udder health status is changing, and always involves time in the denominator. A commonly used mastitis incidence parameter is the number of new cases of mastitis in the milking cows per month. For descriptions of mastitis cases that have a high percentage of spontaneous cure, or for types that have a high removal rate from the herd by culling or death, incidence is a better measure than prevalence. For example, herds that experience cases of environmental mastitis caused by coliform agents should monitor udder health status using incidence rather than prevalence of infection. Measuring mastitis incidence using a whole herd culture approach typical of prevalence determination requires the laborious and expensive task of repeated culturing of individual cows in the herd at regular intervals. Thus it is far more practical and more common to sample cases of clinical mastitis when they occur to estimate mastitis incidence. Monitoring the occurrence of clinical cases of mastitis can be an effective method of determining the changes in udder health status over time, particularly in herds with low bulk milk SCC (Schukken et al, 1989a). The usefulness of calculating incidence for cows that change from under to over a SCC threshold value has been studied (Dohoo and Leslie, 1991). It was found that this method was not a particularly sensitive test on an individual cow basis. However, on a herd basis, it could be useful for the detection of changes in udder health status.

The incidence of clinical mastitis has been compared between high and low SCC herds (Erskine et al, 1988). The incidence was considerably higher in the low SCC herds. Over 50% of bacteriologic isolations from the clinical cases in these herds were caused by either coliform or environmental streptococcal organisms. In the high SCC herds, over 60% of the clinical cases yielded bacteriologic isolation of *Str. agalactiae* or *S. aureus*. It is also noteworthy that over three times as many clinical cases were found to have negative bacteriology in the low SCC herd group. These results support the general conclusion that dairy herd managers should not expect a decrease in the incidence of clinical mastitis as the general herd udder health status and bulk milk SCC improve. In other studies of clinical mastitis in herds with low bulk milk SCC, a similar wide variability in incidence has been reported (Hogan et al, 1989b; Schukken et al, 1989a; Gonzalez et al, 1990). In the Dutch survey the mean incidence was less than the surveys reported from

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North America (Schukken et al, 1989a). Also, the proportion of clinical cases caused by *S. aureus* was substantial at 13.0% (Schukken et al, 1989a), although a case study of one herd in Ohio reported a high incidence of clinical mastitis caused by *S. aureus* in a herd with low bulk milk SCC (Hoblet et al, 1988). Thus there is a great need to implement systems to record and analyze the herd data on clinical mastitis incidence. This information may prove to be extremely useful in making refinements in the mastitis control efforts of the herd.

WHY MASTITIS CONTROL SHOULD BE PART OF A DAIRY HERD HEALTH PROGRAM

The goal of mastitis control is the production of quality milk. Dairy farms are economic enterprises, and thus veterinary practitioners need to engage in areas of dairy cattle health that not only ameliorate animal suffering but also promote economic viability of the dairy as a business. Aspects of the dairy enterprise related to cow health that offer the greatest opportunity for financial and production efficiency should be surveyed. Mastitis causes greater economic losses to the North American dairy industry than any other infectious disease. Much of these losses relate to lost production from inflammation in the infected quarters. Losses, especially with chronic IMI, accrue on a daily basis, and although they are not as dramatic as those resulting from severe clinical cases for the short term, they can be substantial over an entire lactation. SCCs are positively correlated to infection prevalence and thus lost milk production. Conversion of SCC to linear scores provides a direct linear relationship between SCC and potential milk yield losses (Table 10-1).

Although the most substantial loss associated with chronic mammary inflammation is lost production, there are other potential areas of concern for the dairy producer. Many regulatory bodies use SCC as a measure of milk quality and thus establish limits that either serve as criteria for the ability to market milk or initiate monetary penalties for continued marketing of milk over the limit. There are often regulatory limits for raw bacteria counts as well, and in some instances, elevated raw bacteria counts can be caused by a high prevalence of mastitis. In the United States the price that dairy producers receive per pound of protein marketed (multicomponent pricing) is progressively higher for each 50,000 cells/ml increment below 300,000 cells/ml, and progressively lower for each 50,000 cells/ml increment above 400,000 cells/ml (Table 10-2). Many milk cooperatives and processors also pay direct monetary bonuses for quality milk that includes maintaining low SCC and raw bacteria counts in marketed milk (Table 10-2). In addition, some milk marketing cooperatives pay volume bonuses based on the amount of milk marketed by a dairy, but only if the producer maintains the bulk tank SCC below a certain level, usually in the range of 300 to 350,000 cells/ml. Although this varies with marketing cooperatives and local regulatory agencies, incentives that promote the production of quality milk well below that considered adequate for regulatory limits reflect milk buyers' concerns over the lower cheese yield, shelf-life, and higher rancidity associated with higher SCC as well as consumer desire for milk to be a wholesome food product.

As previously noted, death of the cow can occur in more severe cases of clinical mastitis. This generally occurs in a small minority of cases and leaves a lasting, and often exaggerated, impression with dairy farm managers as to the cause of mastitis losses from clinical mastitis. Likewise, dairies that suffer few, if any, deaths from severe clinical mastitis or that have a low incidence of severe clinical mastitis may have the mistaken impression that losses from clinical mastitis in their herd are not important enough to monitor. The two predominant economic losses resulting from clinical mastitis are lost production, which can be difficult to estimate unless daily milk weight technology is used in a herd, and, perhaps more importantly, discarded milk following treatment with antimicrobials. Combined with other expenses such as drugs, labor, and veterinary care, average costs of clinical mastitis cases can range from $100 to

TABLE 10-1

Linear Score Information Table

Linear Score	SCC Range ($\times 10^3$ cells/ml)	SCC Midpoint ($\times 10^3$ cells/ml)	Milk Losses/Day First Lactation (lb of Milk/Cow/Day; Relative to Linear Score 2)	Milk Losses/Day >2 Lactation (lb of Milk/Cow/Day; Relative to Linear Score 2)
0	0-18	12.5	—	—
1	19-35	50	—	—
2	36-71	50	—	—
3	72-141	100	0.75	1.5
4	142-283	200	1.5	3.0
5	284-565	400	2.25	4.5
6	566-1130	800	3.0	6.0
7	1131-2262	1600	3.75	7.5
8	2263-4523	3200	4.5	9.0
9	>4523	6400	5.25	10.5

Adapted from Raubertas RP, Shook GE: *J Dairy Sci* 65:419-425, 1982.
SCC, Somatic cell count.

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TABLE 10-2

*Example of Quality Milk Bonus**

Bulk Tank Somatic Cell Count–(cells/ml; mean for one month)	U.S. Department of Agriculture Federal Order 40 Cheese Price: $1.4163 ($/lb of milk protein)†	Quality Bonus ($/cwt of milk)‡
0-50,000	0.11	0.45
51,000-100,000	0.09	0.35
101,000-150,000	0.07	0.25
151,000-200,000	0.04	0.15
201,000-250,000	0.02	0.05
251,000-300,000	0.01	0.00
301,000-400,000	0.00	0.00
401,000-450,000	− 0.01	0.00
451,000-500,000	− 0.02	0.00
501,000-550,000	− 0.03	0.00
551,000-600,000	− 0.04	0.00
601,000-650,000	− 0.06	0.00
651,000-700,000	− 0.07	0.00
701,000-750,000	− 0.09	0.00
>750,000	− 0.11	0.00

*Current regulatory limit for permit to market grade A milk in the United States is 750,000 cells/ml.
†Varies with milk order (region) and price of cheese.
‡Additional premiums include $0.05/cwt for both a raw bacteria count (standard plate count) of ≤10,000 cfu/ml and a preliminary incubation count (PI) of ≤20,000 cfu/ml. To qualify for premiums, producers may not have during the month: (1) positive drug residues, (2) abnormal freezing point, and (3) rejected load shipment.

$200/case and $40 to $100/cow in herd per year (Hoblet et al, 1991; Bartlett, 1991; Erskine, 1995).

Further losses from mastitis occur from premature culling of cows. This can arise following unsatisfactory convalescence after a severe clinical case, cows that are culled because of recurring clinical cases, or chronically infected cows that contribute high SCC to the herd average. Particularly with respect to contagious pathogens, culling is an important method of decreasing the reservoir of new infections. Lost genetic potential of culled cows and their offspring is possible but is predicated on many unknowns, not the least of which is the ability for the culled cow to propagate viable heifer calves on a regular basis. Other concurrent diseases that may decrease production would enhance the rationale for culling a cow with mastitis. More direct losses are incurred if culling forces the producer to maintain low-producing cows in the herd that preferentially would have been culled, or entering heifers into the milking herd that may have generated income from sale as replacement stock. If expansion is part of the herd plan, culling from mastitis may decrease the ability for a farm to realize cow numbers that fully utilize the physical plant of the dairy or force additional purchases of cows to maintain cash flow.

Finally, mastitis is the most critical disease on dairy farms that affects the incidence of antimicrobial residues in marketed milk. Mastitis is the primary cause of antimicrobial therapy in adult dairy cattle and thus is the primary cause of antimicrobial residues in marketed milk. It is essential for practitioners to integrate mastitis therapy protocols into a health program for dairy herds. Involvement from dairy producers is obtained because of rigorous regulatory monitoring of marketed milk and substantial financial losses for milk that is marketed with violative residues.

Practitioners who convey the economic principles of the benefits of a mastitis control program to dairy clients will more likely secure the monetary investment and time and labor commitment to successfully achieve the production and marketing of quality milk. Herds should attempt to apply universal management practices such as those suggested in Box 10-1. However, in order to design a mastitis control program that will offer the best economic benefits to the dairy farm, practitioners need to develop a program that is best suited to the herd on an individual herd basis, preferably with use of comprehensive herd records. The steps that a practitioner should follow to design a mastitis control program are: (1) to establish goals with the herd managers, (2) to assess if the current mastitis control program is meeting the goals, (3) to implement mastitis control practices that are likely to reduce losses from mastitis, and (4) to establish a monitoring program to evaluate the success of the management changes.

EPIDEMIOLOGY OF MASTITIS

The causation of mastitis involves a complex relationship of three major factors: host resistance, microbial agents, and the environment. Host defense mechanisms are critical in affecting the susceptibility of the dairy cow to udder infection (Nickerson, 1987). However, the characteristics of specific microbial agents and the influence of the environment can also affect development of the disease. The environment of the cow should allow them to be clean, dry, and comfortable. Bedding or other housing conditions that pro-

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vide nutrients to bacteria (organic bedding such as sawdust) or are damp or wet will promote greater exposure of pathogens to the cow's teat end and thus promote a higher incidence of mastitis. Therefore a herd mastitis plan should include provisions to house cows adequately in all stages of the lactation cycle, including the dry period and the maternity pen, and to provide the best possible support to enhance host resistance.

Host Factors

Host characteristics are important risk determinants in the pathogenesis of mastitis (Grommers, 1988). These factors are associated with the development of specific immunity and with nonspecific host defense mechanisms (general resistance). This general resistance by the host relates to genetic predisposition, anatomical characteristics, nutritional status, stage of lactation, parity, and use of management procedures to enhance resistance.

Genetic Resistance

There is ample genetic evidence that the heritability of SCC allows for selection against susceptibility to mastitis (Shook, 1989). There is also evidence of the genetic correlation between milk production and mastitis (Kennedy et al, 1982; Syvajarvi et al, 1986). Selection for milk yield has been accompanied by increased susceptibility to disease (Shook, 1989). It is speculated that long-term selection pressure for milk production may have had a negative effect on the polymorphism of the immune response genes linked to the major histocompatibility complex (BoLA) in the dairy breeds (Lewin, 1989).

Physical Characteristics, Teat Lesions, and Leaking Milk

Anatomical characteristics of the teat and udder affect general resistance to mastitis. Specifically, teat shape is associated with increased risk of clinical mastitis (Van de Geer et al, 1988). Similarly, the integrity of the teat streak canal is important (Jones, 1986). Leaking of milk between milkings has been associated with an increased risk of clinical mastitis (Schukken et al, 1989c; Van de Geer et al, 1988). The presence of continuous milk flow provides a route for invasion from the environment into the teat cistern. Teat-end lesions operate on a similar principle as an important risk factor for mastitis (Dohoo et al, 1984a).

Stage of Lactation

Stage of lactation is a determinant of both subclinical and clinical mastitis. Mastitis caused by environmental organisms, such as clinical coliform infection, is most common in the first few days after calving and occurs less as lactation progresses (Erb et al, 1984; Erskine et al, 1988; Hogan et al, 1989b; Schukken et al, 1989a). General immune function and the mammary influx of leukocytes both markedly decrease shortly after calving (Kehrli et al, 1989). In addition, humoral defense mechanisms that have increased in the dry period suddenly decrease after calving (Nickerson, 1989a). Increased serum cortisol concentrations at calving are also associated with decreased glucocorticoid receptor expression, which results in decreased L-selectin expression in neutrophils (Preisler et al, 2000). L-selectin is a critical membrane protein necessary for neutrophil margination and diapedesis into a site of inflammation, such as a mastitic quarter. This offers a molecular rationale for increased susceptibility of cows to mastitis in the periparturient period and supports earlier research that noted the decreased ability of recently calved cows to recruit neutrophils into the mammary gland during severe coliform mastitis (Hill et al, 1979). On the other hand, the prevalence of subclinical infections increases as the stage of lactation progresses. These infections are generally the result of contagious mastitis pathogens, such as *S. aureus*. This is caused by an inability of mastitis control efforts to limit cow-to-cow transmission of organisms rather than by a physiological effect.

Parity

Increasing parity is a risk factor for increased incidence of clinical mastitis as well as for an increased prevalence of subclinical infections (Dohoo et al, 1984b; Schukken, 1989c). Although heifers are often subjected to different management practices than older cows before calving, they should have equal exposure to pathogenic microorganisms as milking animals. Younger cows may have a decreased susceptibility to mastitis because they may have a more effective host defense mechanism. They have significantly better polymorphonuclear leukocyte function than multiparous cows (Dulin et al, 1988). On the other hand, Hogan et al (1989b) found the highest incidence of clinical mastitis in first-lactation animals.

Nutrition and Periparturient Diseases

Proper feeding of the peripartuient cow affects the incidence of numerous metabolic diseases. Periparturient diseases, such as dystocia, parturient paresis, retained placenta, and ketosis have all been identified as risk factors for the subsequent development of mastitis. In a study of 137,000 calvings, cows experiencing dystocia had a 1.5 times increased risk of clinical mastitis (Bendixen, 1988). Multiparous cows with parturient paresis had a fivefold higher risk of developing clinical mastitis compared with multiparous cows without parturient paresis (Curtis et al, 1983, 1985). Animals that retained the placenta were two to three times more likely to develop mastitis (Bendixen, 1988; Schukken et al, 1989c). In studies by Dohoo and Martin (1984a) and Syvajarvi et al (1986), animals with a history of ketosis were at increased risk of mastitis. The biological explanations for these associations but have not been explained definitively.

Colonization with Minor Pathogens

There may be broad effects of management intervention and mastitis control practices on host resistance. For example, the long-term use of postmilking teat disinfection has been hypothesized as a risk factor for clinical mastitis in low SCC herds. The increased risk is thought to result from a reduction in the prevalence of minor pathogens (Hogan et al, 1987; Robinson et al, 1983; Schukken et al, 1989a). Studies have been designed to decrease the infection opportunity by major mastitis pathogens through colonization of the glands with minor pathogens, such as *C. bovis*. These experiments have shown both decreased (Brooks and Barnum, 1984; Matthews et al, 1989) and increased incidence (Hogan et al, 1988b) of infections by major organisms. A field trial involving four herds with moderate levels of infection demonstrated that premilking teat disinfection in combination with a postmilking teat dipping program decreased the incidence of infection with environmental pathogens (Pankey et al, 1987). The whole subject of infections with minor pathogens providing a protective effect against the development of infection with a major organism still requires considerable elucidation.

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Immune Modulation

Immune modulation has been attempted in order to enhance mastitis resistance. In a field study of 13 farms using recommended mastitis control programs, cows with the physical immunostimulation provided by an intramammary device were observed to have a 4.6 times lower incidence of clinical mastitis than cows without the device (Paape et al, 1988). Other attempts at nonspecific immunostimulation to prevent mastitis have been described for levamisole (Anderson, 1984); concanavalin A (Oliver and Sordillo, 1989), interleukin-2 (Nickerson, 1989a), and thymosine (Kehrli et al, 1989). Most methods of nonspecific immunostimulation have only been tested under experimental conditions. Field trials for many prospective immune modulators have not been described or have proved to have less than desirable results (Hogan et al, 1995; Erskine et al, 1998a).

Vaccination

A great deal of research has been aimed at improving the specific resistance of dairy cows to mastitis by vaccination to produce immunity against the major mastitis organisms (Colditz and Watson, 1985). Most of this research has focused on the prevention of *S. aureus* and *Escherichia coli*. Vaccines against *S. aureus* mastitis have been developed in Australia (Colditz and Watson, 1985; Frost and Mattila, 1988) and have shown some promise against experimental challenge. A field trial was conducted to evaluate the efficacy of *S. aureus* mastitis vaccine developed against pseudocapsular components of the pathogen in commercial dairy herds in Australia (Watson and Schwartzkoff, 1990). Even with considerable herd-to-herd variation, there was an overall reduction in *S. aureus* clinical cases and in the levels of subclinical mastitis. This represents a considerable improvement over previous staphylococcal mastitis vaccines. However, longer-term studies are necessary for the validation of these findings and for the support of cumulative improvement with several years of vaccination in a herd.

Field trials using a mutant *E. coli* J5 (core-antigen) vaccine have shown a decrease in the incidence of coliform mastitis (Gonzalez et al, 1989; Cullor, 1991). Both of these trials used an untreated group for the control. Further studies with experimental *E. coli* infections have supported the belief that vaccination with core-antigen vaccines decreases severity of infections. Commercial products that use this technology have become available and will be discussed in greater detail in the section regarding environmental mastitis.

SCREENING TESTS FOR DETECTING MASTITIS

In order to select an appropriate screening test and to interpret the results of the test properly, it is important that the test be evaluated with epidemiologically sound criteria. The sensitivity, specificity, predictive value, and efficiency of a test are helpful in determining the appropriate situations for its use. In the context of a mastitis screening test, sensitivity is the ability of the test to yield a positive result when the cow actually has mastitis. The specificity of a test is its ability to discern that an animal is actually negative for mastitis.

It is essential that an excellent method of determining true mastitis status be used in order to have a meaningful evaluation of the sensitivity and specificity of the screening test. For most evaluations of mastitis screening tests, milk bacteriology has been the gold standard. However, there are situations in which culture results may not provide the best assessment of the true status. Some of these situations are described later in this chapter.

For tests with a continuous numerical result, such as SCC, a threshold value is used to classify the result as positive or negative. Selection of the threshold level can greatly affect the sensitivity and specificity of the test. A mastitis screening test with a high sensitivity can reduce the number of cows incorrectly classified as negative (false-negatives). A highly specific test reduces the false-positive rate (those animals incorrectly classified as having mastitis). The choice of the threshold value depends on the purpose of the test. For example, the use of SCC data to select cows for dry period therapy would favor a high sensitivity, with minimal false-negative results. Thus the threshold would be lowered to enhance the test sensitivity. This would ensure that as many infected cows as possible would be dry treated, even at the expense of treating some false-positive (uninfected) cows. On the other hand, the use of SCC in culling decisions would favor a highly specific test with a low false-positive rate. In this situation a higher threshold would be used to improve the reliability that a high SCC cow truly had mastitis. A schematic representation of the relationship of sensitivity to specificity and the importance of the threshold value is shown in Fig. 10-1.

The sensitivity and specificity provide information about a mastitis screening test while assuming a known rate of mastitis in the population. However, it is much more common to have the test result and to desire information about the state of the disease in the population. In other words, what is the predictive value of the test? The predictive value of a test depends on its sensitivity, specificity, and prevalence of the disease in the herd. The positive predictive value (PV+) is the probability that a cow with an SCC over the selected threshold is infected. The negative predictive value (PV−) is the probability that a cow with an SCC under the threshold is not infected. The proportion of cows in the herd that have mastitis greatly affects these values. As the prevalence of infection in the herd increases, the positive predictive value increases and the negative predictive value decreases. In other words, in a herd with a high prevalence of mastitis, the likelihood of a cow over the 250,000 SCC threshold value being infected is greater.

The efficiency of a screening test is the total percentage of all cows that are correctly classified as to infection status with the test result. The overall efficiency of a test, such as SCC, is not particularly meaningful, because it is unaffected by changes in prevalence and is relatively constant.

In summary, appropriate implementation of a mastitis screening test into an udder health management program depends on an understanding of the characteristics of the test. In a particular herd situation, the usefulness of a specific test depends on its sensitivity, specificity, and predictive value. Care must be taken that the "gold standard" used to determine screening test performance is the best estimate of true mastitis status in each particular situation.

Milk Bacteriology

Incubation of a standard volume of aseptically collected milk that has been streaked on an agar culture medium has been the standard diagnostic method for bovine mastitis for many years. The resulting bacterial growth is observed, quantified, and tested. Standard microbiological procedures for use in the diagnosis of bovine mastitis have been widely adopted. In fact, the use of milk culture is widespread as a means to determine udder health status. It is the definitive, standard diagnostic test for determining if an infection exists as well as the causative agent.

Many countries have developed a regional system of diagnostic laboratories dedicated to the bacteriologic culture of milk. The standard methodology used in most of these laboratories involves an individual milk sample being streaked

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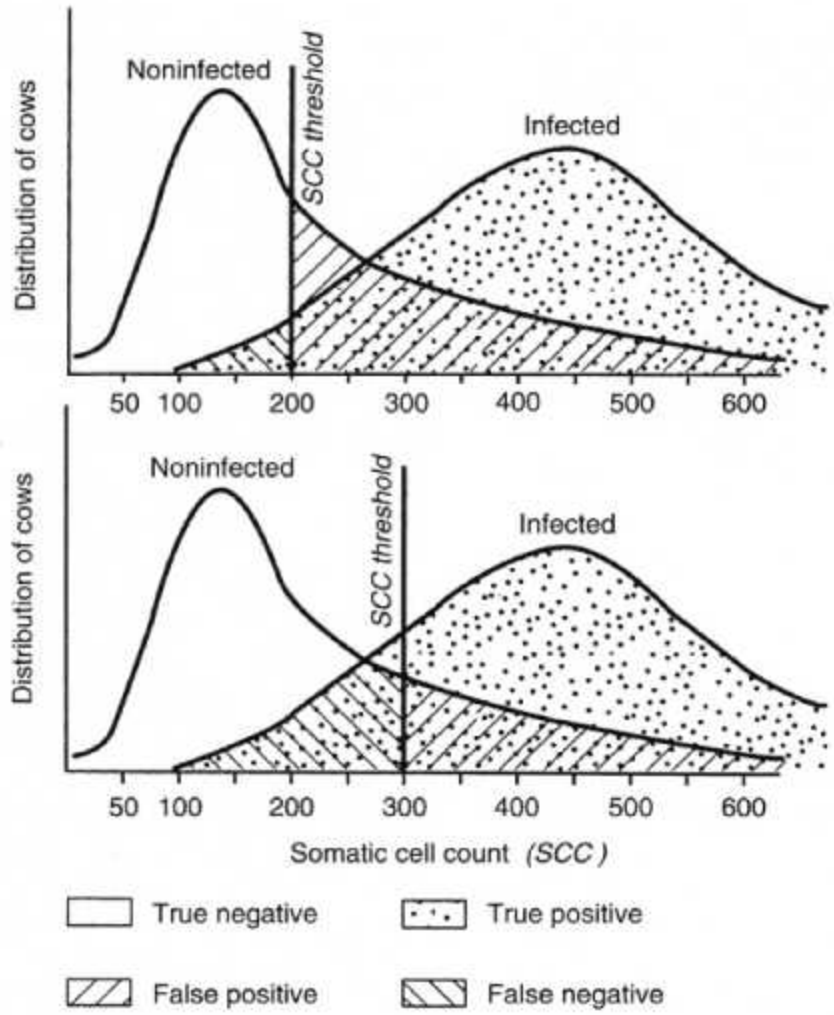

FIG. 10-1 Schematic representation of the effect of changing the somatic cell count threshold value for the classification of cows as positive or negative.

onto one of four quadrants of a blood agar plate with the use of a sterile cotton swab or flamed loop. The plates are incubated at 37° C for 18 to 24 hours and longer for slow-growing organisms. Identification of organisms is done by colony morphology, microscopic examination, and further laboratory tests. Effective use of these culture results can play a major role in the improvement of udder health status at the individual cow and herd levels.

Although the microbiological culture of milk has become the undisputed standard diagnostic procedure in mastitis control, there are several key points to be considered. Relative to other tests, such as SCC, bacteriology is labor intensive and expensive to conduct. Furthermore, even though milk culture is assumed to be the standard test, it has seldom been subjected to formal epidemiological methods of test evaluation. The sensitivity, specificity, and predictive value of bacteriologic tests for diagnosing subclinical contagious mastitis has been reviewed (Jensen and Knudsen, 1990; Buelow and Nordlund, 1999). Diagnostic procedures that are based on the bacteriologic examination of single foremilk samples have a low positive predictive value for the diagnosis of infectious subclinical mastitis, especially *S. aureus*. Even in combination with a fixed SCC threshold value to determine positive cows, milk bacteriology has a low sensitivity for minor pathogens.

Isolations of bacteria from milk samples can be difficult to interpret. The isolation may be a result of teat streak canal colonization or of overt contamination in the sampling process. The least amount of errors occur when a diagnosis is categorically based on bacteriology alone (Neave, 1975). However, a completely objective reference method was not used to evaluate bacteriologic tests. The quantification of the number of colonies recovered cannot be strictly interpreted as a measure of diagnostic sensitivity. For example, a milk sample yielding 400 colonies of *Str. agalactiae* can be equivalent to a sample with a culture result of only a few colonies (Villanueva et al, 1991).

For contagious mastitis pathogens, identification of all infected cows, and on some occasions infected quarters within a cow, is important in the overall control effort. The standard definition of an IMI is the isolation of a pathogen from two of three consecutive milk samples collected from a quarter on from three separate collection dates. Particularly for environmental pathogens, the probability for contamination of one sample is great enough to warrant concern over false-positive results unless the isolation is repeated on a subsequent culture. However, false-positive results occur infrequently enough with contagious pathogens that one positive isolation is considered indicative of an IMI. Repeated sampling of quarters can be labor intensive, thus one alternative is to use the collection of duplicate milk samples collected at the same time and isolation of the pathogen in both samples as being indicative of an IMI. Alternatively, composite samples collected and mixed from all four quarters of a cow are easier to collect and cause less cultural needs. The chance of contamination is higher however, and this method should really only be used to identify potentially infected cows with contagious pathogens (low false-positive rate) and perhaps as a screening test for IMI caused by more chronic pathogens such as *Streptococcus uberis*, although follow-up sampling would be suggested to confirm the presence of IMI caused by environmental pathogens. Because *Str. agalactiae* tend to be shed in high concentrations in milk from infected quarters, the sensitivity of a single

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composite milk sample to detect an IMI is greater than 95% (Dinsmore et al, 1991). However, chronic *S. aureus* infections have been shown to have a periodic shedding pattern, and if negative results are obtained after culture, serial samples should be collected at least two more times in order to detect a positive quarter (Sears et al, 1990b; Daley, 1991a). Freezing of milk samples before bacteriologic testing has been shown to increase the isolation rate of contagious pathogens (Villanueva et al, 1991; Schukken et al, 1989b), which reflects the release of intracellular pathogens following lysis of phagocytes.

To have a profile of the organisms causing clinical mastitis in a herd, it is recommended that milk samples be collected aseptically from each clinical case before treatment and that the samples be stored by freezing. At a convenient time, such as a scheduled health management visit, the frozen samples should be gathered and cultured. The incubation of mastitic milk samples before bacteriologic culturing can be used to decrease the negative culture rate from clinical cases (Schukken et al, 1989b). In cases of clinical mastitis caused by environmental organisms, negative bacteriologic culture findings are common.

Bacteriologic culture of bulk tank milk can be a useful indicator of udder health status at the herd level. Regular, repeated cultures of a standard volume of bulk milk on selective media can be useful for determining the presence of *Str. agalactiae, S. aureus,* and *M. bovis* (Godkin, 1990). The value of bulk tank cultures for determining the presence of environmental pathogens is limited because of potential contamination, and almost all herds have cows infected with streptococci and staphylococci at any point in time. Likewise, care should be taken in trying to assess the prevalence of IMI in a herd based on bacteria counts from bulk tank culture. Sampling of individual cows and monitoring the proportion of cows with elevated SCC is more accurate.

In summary, milk bacteriology continues to be recognized as the definitive test for determining infection status in mastitis research and udder health management programs. This widespread use of bacteriology is perfectly acceptable as long as its epidemiological characteristics and limitations are considered. Contagious pathogens are not frequently associated with false-negative results; however, negative isolations from suspected infected cows may warrant repeat culture to increase the sensitivity. Pure isolations of any pathogen collected from quarters of clinical mastitis cases can be used as an identification of etiological agent. However, routine culture of environmental pathogens, especially from subclinical cows or quarters, and those with low linear SCC should be suspected as contaminants, and follow-up samples or duplicate samples collected at the initial sampling should be cultured to improve specificity.

Somatic Cell Counts

The counting of somatic cells excreted in the milk has become a widely used indirect measure of mammary gland inflammation. Somatic cells (predominantly neutrophils, as well as other leukocytes and epithelial cells) enter the mammary gland as a result of damage to the alveolar lining by infection or chemical irritation. The cells can be counted by a laborious direct microscopic method on stained milk smears. The cell numbers can also be estimated by indirect chemical tests. However, the electronic enumeration of cell numbers in either preserved or fresh milk samples has revolutionized the potential for monitoring udder health status (Meek and Barnum, 1982). The most commonly used automated device for rapid determination of the SCC in milk samples is the Fossomatic milk cell counter (Foss Electric, Hillerod, Denmark). This instrument stains cells with a fluorescent dye and then counts the number of fluorescing particles. This electronic technology is capable of the rapid, inexpensive determination of SCC in large numbers of samples. The instrumentation can be linked electronically to large computer data files. This has allowed DHI organizations to develop programs for the routine screening of preserved composite milk samples from individual cows. Bulk tank milk samples are routinely tested for SCC by regional regulatory laboratories and milk cooperative facilities.

Factors Affecting Somatic Cell Counts

The correct interpretation of SCC data depends on an understanding of the factors that influence the number of cells in milk at the quarter, cow, or herd level (Dohoo and Meek, 1982). The factor with the greatest effect on SCC is intramammary infection. In comparison, all the other factors that affect SCC are of only minor importance. There are considerable differences in mean SCC levels from composite milk samples of individual cows, according to their infection status. Cows that are free of infection have significantly different mean SCC levels than those with major or minor mastitis pathogens. However, within each of these groups the SCC is widely variable (Dohoo et al, 1981). There is even some variation in SCC response elicited by various major pathogens, yet it is not possible to distinguish among the pathogens on the basis of SCC alone. The SCC of an individual cow composite sample depends on the number of quarters infected, the severity of infection in each quarter, and the respective milk production of each quarter. The dilution of high SCC milk from infected quarters with low SCC milk from uninfected quarters is an important consideration in the interpretation of a composite sample cell count.

The practical use of SCC data to determine cow infection status requires the selection of a threshold level. The importance of threshold selection has been described previously. If the aim of monitoring SCC is to detect cows that may only have subclinical mastitis in one quarter, then the use of an SCC threshold value of 200,000 cell/ml appears to be reasonable (Dohoo and Meek, 1982). Fig. 10-1 illustrates the effect of selection of a threshold value on the occurrence of false-positive and false-negative classifications.

Factors other than infection can cause a substantial SCC increase. Chemical irritants, such as antibiotic therapy, can cause raised SCC. Trauma to the udder can also cause higher than normal SCC levels. Experimentally induced stress on individual cows has resulted in higher SCC. The time and method of sampling may affect the resulting SCC value. For example, counts are lowest immediately before routine milking and are highest in stripping samples. Samples at evening milkings are somewhat higher than in the morning. There is considerable variation in SCC of an individual cow from day to day. The reasons for this diurnal variation include fluctuations in production, spontaneous elimination of new infections, unobserved udder injury, stress, and inherent biological variation of individual cows. Therefore it is prudent to draw conclusions from a series of SCC values rather than to base an interpretation on one mildly elevated count.

On a regional basis, bulk milk SCC monitoring programs have shown some seasonal variation, with cell counts higher in summer and early fall than in winter or early spring (Dohoo and Meek, 1982). This seasonal variation is not large, and has been attributed to the increased stress of cow movement on the udder resulting from the pasture and loose housing systems used in the summer months, and to

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greater numbers of environmental bacteria in the bedding of cows (Smith et al, 1985c).

Two of the more substantial factors affecting the SCC of individual cows are age and stage of lactation (Dohoo and Meek, 1982). As cows become older, the SCC is generally higher. This SCC elevation results from an increased prevalence of subclinical infections with age, a greater cellular response to infections in older cows, and an increased amount of residual damage from previous infections. In cows that have never had an intramammary infection, however, there is no increase in SCC with age. Considerable variation in SCC occurs relative to the stage of lactation. Greatly elevated counts are observed immediately after calving. The SCC returns to normal at approximately 8 to 14 days postpartum. Counts also rise just before drying off, as milk production decreases markedly. The observed increase in SCC that tends to occur as the stage of lactation progresses is probably caused by an increased prevalence of subclinical infections in later lactation. There is no evidence that SCC changes throughout lactation, provided IMI does not occur. In other words, in herds that have a low prevalence of infection by having controlled contagious pathogens, there should be little evidence of change in the SCC distribution with stage of lactation.

Some technical factors, such as method of transportation, use of milk preservatives, time in storage, and type of cell counting instrument can affect SCC values. However, these technical factors are unlikely to be important in any routine SCC monitoring program.

The interpretation of SCC data as a measure of infection status for problem solving and decision making in udder health management programs require consideration of all factors affecting the SCC.

Epidemiological Evaluation of SCC

The SCC has been epidemiologically as a screening test for subclinical mastitis in individual cows, using bacteriology as the standard test (McDermott et al, 1982; Dohoo et al, 1981). At a threshold value of 200,000 cells/ml, the sensitivity of the SCC for determining infection is approximately 80%. In other words, roughly 20% of infected cows have SCC levels of less than 200,000 cells/ml. The specificity of SCC at this threshold is approximately 75% to 80%. That is, 20% to 25% of noninfected cows have SCC levels greater than 200,000 cells/ml. As described earlier, the SCC threshold can be changed to improve specific decision-making purposes, such as selection of cows for dry cow treatment or for culling. Using a threshold of 200,000 cells/ml, the sensitivity and specificity values discussed show that SCC is a helpful screening test. The prevalence of mastitis (cow infection rate), however, changes the predictive values. As the prevalence of infection in the herd goes up, the positive predictive value of SCC also goes up. In other words, a cow over 200,000 cells/ml is more likely to be infected. However, the negative predictive value is reduced because cows under 200,000 cells/ml are less likely to be free of infection. Over a range of cow infection rates from 5% to 50%, the efficiency of SCC as a screening test changes little (75% to 78%, respectively). Efficiency is the total percentage of all cows tested that are correctly classified as to infection status at the chosen threshold (Dohoo et al, 1981). Eberhart et al (1982) emphasized that additional insight into the probability of a cow being infected was gained by knowing the actual SCC magnitude, as opposed to knowing only the status relative to the chosen threshold. As the SCC increases over the threshold, the probability of infection with a major pathogen also increases.

Somatic Cell Counts Converted to Linear Scores

Somatic cells are measured as thousands of cells per milliliter of milk and can range from tens of thousands to many millions. Converting the actual SCC to a natural logarithmic scale (linear score) can improve the usefulness of SCC for herd management purposes. Linear scores (LS) reduce the SCC to a scale ranging from 0 to 9. The corresponding values for SCC and LS are shown in Table 10-1. An increase of one unit in LS corresponds to a doubling of SCC. For example, the midpoint for LS3 is equal to a 100,000 SCC, LS4 to a 200,000 SCC, and LS5 to a 400,000 SCC. Any individual SCC can be converted to an LS value.

There are two major advantages for using LS rather than raw SCC values. First, there is a consistent, linear relationship between an increase in LS and milk production losses (Raubertas and Shook, 1982). The estimates of milk loss with each unit increase in LS are presented in Table 10-1. Second, the major advantage of using LS is in the averaging of counts. An average of several SCC values is more useful for analysis and interpretation than a single value. However, one extremely large SCC value can have a great effect on the average. An average of LS more accurately represents the lactation average of an individual cow or the average of a particular management group. Thus average LS values are more effective for mastitis management purposes. This advantage is particularly important in small herds. A worksheet that provides a method to calculate potential production losses from mammary inflammation based on individual cow LS is presented in Chapter Appendix A (p. 432).

Fig. 10-2 is an example SCC report provided by the Dairy Records Management Systems for a dairy herd in Michigan.* Fig. 10-2, *A* (SCC Profile DHI-520) provides a herd average SCC and a summary of individual cows in the herd. The owner may choose actual or linear SCC for the individual cows. Actual scores are provided in this report, and data are presented for the last six test dates. If a cow was one of the 26 cows in the herd with an SCC above 200,000 cells/ml (LS >4.0) in the current test month, she was classified as having a new or chronic (two or more consecutive test dates ≥200,000 cells/ml) IMI. Chronic cows based on this report are likely to be infected and would make excellent candidates for sampling for culture. Cows are ranked from those with the highest contribution to the bulk tank SCC on the top (cow no. 31; 19%) to the lowest SCC contributors on the bottom (Sally; <1%). This ranking is a function of SCC and milk production so that culling decisions based on SCC alone would be tenuous; however, a within herd classification on 305-day mature equivalent production is also provided for each cow. Cows with an "A" ranking are superior cows within the herd, the "E" cows the most inferior. Thus, from a standpoint of SCC, cow no. 45 and Connie would be good candidates to be on the cull list. Cow no. 31 is contributing 19% of the bulk tank SCC, but she is a better-than-average cow for production and had a marked elevation in SCC since the last test. A history of this cow regarding possible clinical mastitis, and a culture of a milk sample to identify the causative agent would be helpful. Cow no. 85 has only one test and has not yet displayed a chronic IMI. However, this cow is a second-lactation animal, and previous lactation records should be examined to determine if the current IMI was continued through the dry period, in which case this cow would also be a good candidate to be on the cull list. Additional information regarding causative pathogen, breeding history, and other health problems would also need to be weighed into the decision. Fig. 10-2, *B* (SCC summary DHI-521) provides a distribution of LS, a

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SOMATIC CELL COUNT PROFILE DHI-520

HERDCODE 12345678 JOHN DOE

SCC SCORE TO ACTUAL CONVERSION CHART

SCCS	Cell Cnt (1000)	SCCS	Cell Cnt (1000)	SCCS	Cell Cnt (1000)
0	0-18	4	141-283	8	2,262-4,523
1	19-35	5	284-565	9	4,524-9,999
2	36-71	6	566-1,130		
3	72-141	7	1,131-2,262		

SCC OPTION SCORE ACTUAL: ACTUAL (NEAREST 1000)

DATE OF TEST: 03 15 99 PAGE 1

HERD AVG SCC COUNT: 782

SORTED BY % OF BULK TANK SCC

BARN NAME OR COW INDEX	TEST DAY MILK		SOMATIC CELL COUNT						MASTITIS INFECT. *	% BULK TANK SCC	AV. SCC W/O THIS COW & COWS ABOVE THIS COW	LACT. AVG. SCC SCORE	#SCC TESTS THIS LACT.	#TESTS OVER 3.9 SCC SCORE	DAYS IN MILK	DUE DATE	LACT. NO.	RATING
	PREVIOUS	CURRENT	TEST DATE 08-20	TEST DATE 10-01	TEST DATE 11-11	TEST DATE 12-18	TEST DATE 01-27	THIS TEST										
31	94	56					429	3676	CHR	19	653	6.7	2	2	79		3	B
45	39	33					3676	4223	CHR	13	556	8.3	2	2	70		5	E
CAROL	66	44			81	246	7352	2786	CHR	12	473	6.0	4	3	140		3	C
CONNIE	42	42					1600	2986	CHR	11	381	7.5	2	2	82		8	E
69		38						1300	NEW	5	349	6.7	1	1	29		2	
15		25						1970	NEW	4	312	7.3	1	1	10		1	
68		29						1300	NEW	3	284	6.7	1	1	8		1	
37		29						1131	NEW	3	260	6.5	1	1	34		2	
11	48	55					100	650	NEW	3	238	4.4	2	1	78		2	C
LINDSEY	68	46				650	2111	492	CHR	2	225	6.1	3	3	106		3	D
56	31	12	246	214	246	200	187	1056	CHR	1	214	4.3	6	5	363		2	D
89	22	21	528	919	857	492	429	857	CHR	1	199	5.8	6	6	383	3-29-99	2	D
14		27						746	NEW	1	181	5.9	1	1	7		2	
33	35	28	283	429	348	528	246	429	CHR	1	173	5.6	6	6	447		3	A
24	71	45		13	132	123	174	246	NEW	1	169	3.0	5	1	178		3	A
53	24	10	4851	2786	1393	746	4223	919	CHR	0	160	7.5	6	6	411	6-22-99	4	D
52	37	10	348	528	650	373	132	696	CHR	0	153	3.6	6	5	429	5-28-99	3	C
58	35	17	54	13	13	17	54	325	NEW	0	149	1.4	6	1	350	6-18-99	2	A
REBA	20	19	200	214	303	325	325	303	CHR	0	145	4.3	6	6	356		3	D
44	50	30	200	200	132	115	303	264	CHR	0	140	3.9	6	4	245		2	D
85	41	27	696	460	230	246	152	264	CHR	0	135	4.7	6	5	294	6-22-99	2	B
16	20	21	162	303	174	200	162	230	NEW	0	132	5.1	6	3	448	6-25-99	2	C
27	50	27		123	303	123	162	230	NEW	0	127	3.8	5	2	210		3	C
38	29	21	9701	303	93	187	152	230	CHR	0	124	4.3	6	3	304	6-26-99	2	C
MICHELL		38						230	NEW	0	117	4.2	1	1	28		2	
57		31						214	NEW	0	111	4.1	1	1	23		1	
39	50	34		1715	141	87	162	187		0	106	4.2	4	1	208		4	C
73	31	17	528	187	132	303	123	187		0	103	3.9	5	2	610	6-18-99	1	A
96		21						174		0	100	3.8	0	0	21		1	
93	48	24	62	141	132	76	41	162		0	96	2.7	5	0	610		1	A
13	41	48		246	107	123	200	141		0	91	3.6	4	2	208		4	B
97	57	53					62	141		0	83	2.9	1	0	79		2	D
MISTY	39	23	325	214	373	187	187	132	PRV	0	79	4.0	5	3	347	6-18-99	2	E
9	52	46		13	141	162	93	123		0	72	2.7	4	0	178	9-17-99	4	B
7	55	37	283	214	400	100	81	115	PRV	0	65	4.0	5	3	386		2	A
81	41	25	41	141	123	93	87	107		0	60	2.9	5	0	239		2	E
22	48	31	76	13	93	81	66	100		0	53	2.3	5	0	220		2	C
18	61	80					246	57		0	50	3.3	1	1	57		2	A
63	55	37		141	13	35	141	57		0	46	2.1	4	0	176		2	B
92		25						54		0	41	2.1	0	0	25		1	
SALLY	37	34	57	115	162	35	41	41		0	0	2.8	5	0	368	6-01-99	1	D

* NEW * Animals with SCC Score >4 (200,000) for the first time this lactation.
* CHRONIC * SCC Score >4 (200,000) this test, and 2+ consecutive test dates this lactation.
* PRV * SCC Score >4 (200,000) 2+ consecutive test dates this lactation.

FIG. 10-2 (A-C) Dairy Records Processing Center dairy herd improvement somatic cell count *(SCC)* cow reports and herd SCC summaries. (Courtesy of Dairy Records Processing Center, Raleigh, NC.)

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HERDCODE	DATE OF TEST
12 34 5678	05 20 01

SOMATIC CELL COUNT SUMMARY DHI-521

Herd Average SCC By Test Day

	Test Day 05-06	Test Day 06-04	Test Day 07-07	Test Day 08-20	Test Day 10-01	Test Day 11-11	Test Day 12-18	Test Day 01-27	Test Day 03-15	Reg. Av. Top 25%
Weighted Av. SCC	2024	1557	438	901	473	374	258	911	782	162
Av. Linear Score	5.3	4.7	4.1	4.8	4.3	4.3	4.2	4.4	4.8	2.1

SCC Summary

SCC Actual	SCC Score	Animals	Herd %	Reg. Top 25%
< 100	< 3.1	5	12	70
100-200	3.1-4.0	10	24	15
201-400	4.1-5.0	10	24	6
401-800	5.1-6.0	5	12	4
> 800	> 6.0	11	28	3

Milk Loss Per Day

	Per Milking Cow	Per Herd
Lbs	4.5	184
Dollar	$0.72	$29.57

Stage Of Lactation Profile

	Lact #	Days in Milk This Test Day: 1 - 40	41 - 100	101 - 199	200 - 305	306 +	Total	Reg. Av. Top 25%
Number Cows	1	8				3	11	31
	2	4	3	1	5	6	19	23
	3+		3	4	3	4	14	33
	All	12	6	5	8	13	44	87
Average Milk	1	26				25	25	49
	2	33	63	37	27	22	36	66
	3+		44	45	36	17	35	71
	All	29	53	41	31	21	35	63
Average SCC Score or Actual	1	753				113	600	140
	2	843	254	57	192	369	345	180
	3+		3596	895	178	503	598	225
	All	798	1626	751	185	330	782	162
% > 3.9 SCC Score (200,000 Actual)	1	60					37	10
	2	100	33		60	66	63	12
	3+		100	75	33	100	78	16
	All	77	66	60	50	61	63	15
Number New Infect.	1	3					3	
	2	4	1			2	7	
	3+			1	1		2	
	All	7	1	1	1	2	12	
Number Chronic Infect.	1							
	2				3	2	5	
	3+		3	2		4	9	
	All		3	2	3	6	14	

FIG. 10-2, cont'd For legend, see p. 406.

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C

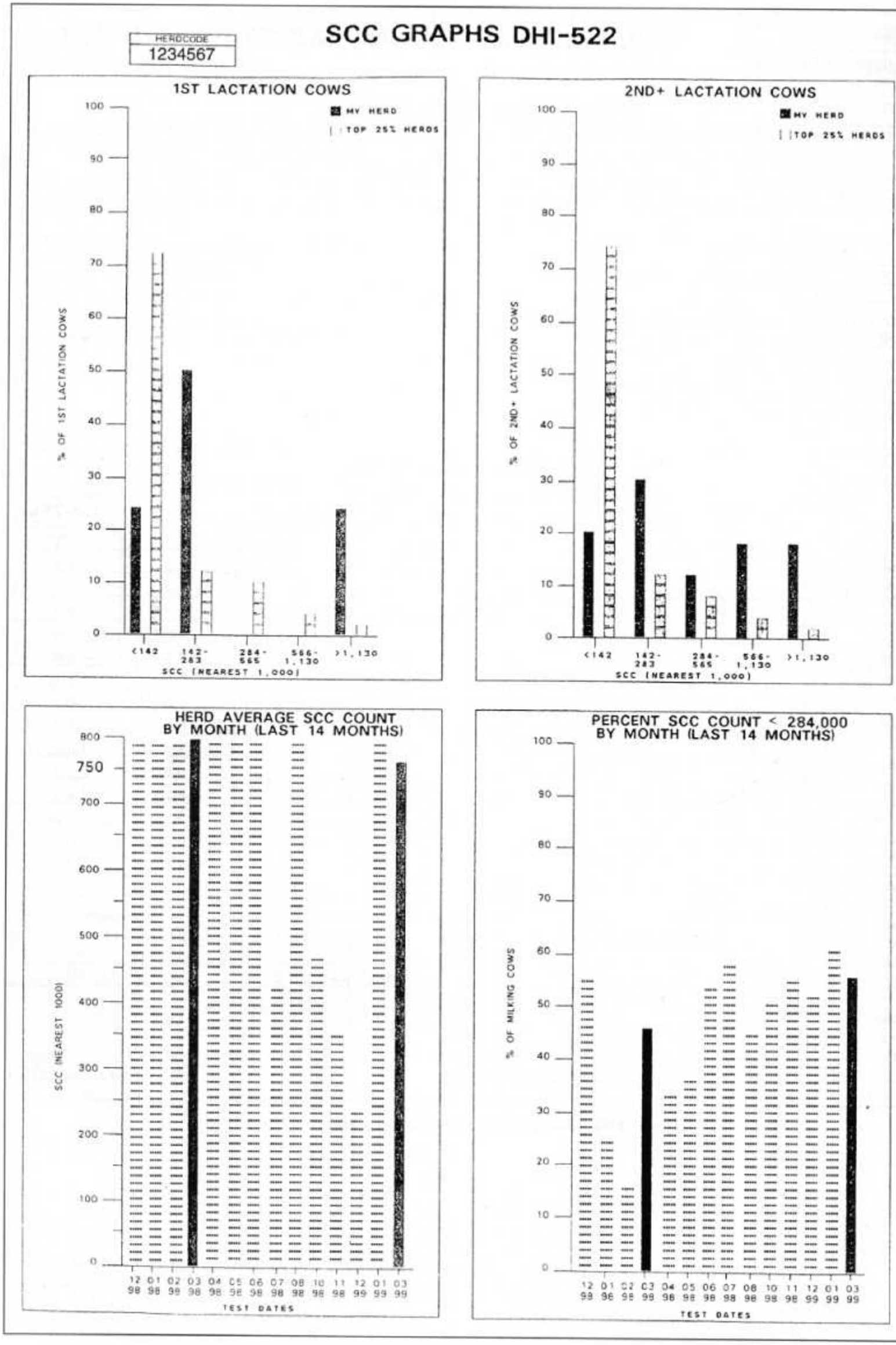

FIG. 10-2, cont'd For legend, see p. 406.

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profile of LS by days in milk and lactation number, and an estimate on milk loss per day for each cow and the entire herd. Fig. 10-2, *C* (SCC graphs DHI-522) provides graphic comparisons of the test herd to the best 25% of the herds in the state and SCC for the last 14 months.

Summary: Interpretation and Use of Individual Cow Somatic Cell Count

It is important to choose a threshold SCC value to suit the management purposes of the mastitis control program. In most herds, 200,000 cells/ml detects approximately 80% of infections and correctly classifies 75% to 80% of noninfected cows. At any threshold, infected cows can be missed and negative cows can be classified incorrectly as infected. The probability that a cow is infected goes up with the magnitude of the cell count. For any given SCC, the probability that the cow is infected varies according to the prevalence of subclinical mastitis in the herd. The interpretation of a series of SCC values over time is more effective than the evaluation of a single count. Regardless of the infection status, the SCC is an excellent indicator of udder health status. The natural logarithmic conversion of SCC to a linear score is useful for herd management purposes. Linear scores are directly related to milk production losses. An average of LS removes the problem of the adverse effect of one or two extreme SCC values on the raw SCC average. The reporting by DHI organizations of SCC and LS data on individual cows, and in a variety of herd summary graphs and tables, has become an important tool in describing the extent of subclinical mastitis and in serving as a selection criteria for determining which cows should be sampled for culture.

Other Diagnostic Tests

Several other diagnostic tests have been developed to detect intramammary inflammation. This is accomplished by measuring milk somatic cells indirectly or by determining the concentration of various by-products of the inflammatory response. Many of these tests have been compared formally for detecting mastitis (Emanuelson et al, 1987). Some of the tests may have a role in mastitis control programs, either as rapid cowside methods to determine which quarter is infected or as automated in-line detection methods for milking parlors.

California Mastitis Test

The California Mastitis Test (CMT) involves mixing and swirling equal parts of bromcresol violet reagent and milk in a plastic paddle with a compartment for each quarter. This test is inexpensive and extremely portable. The test results are interpreted subjectively as either a negative, trace, 1+, 2+, or 3+ inflammatory response based on the viscosity of the gel formed by mixing the reagent with the milk. The CMT can be a useful adjunct to laboratory screening tests performed on composite milk. For example, individual cows that are positive on composite sample DHI SCC results can be checked with a CMT. This determines whether the cow has remained positive in the lag time since the DHI laboratory SCC test was conducted. In addition, the CMT is also useful to determine which quarters are positive. Cows with mild clinical changes in a mammary gland, but with no abnormalities in the milk, can be evaluated readily using the CMT.

N-Acetyl-β-D-Glucosaminidase (NAGase)

The milk *N*-acetyl-β-D-glucosaminidase (NAGase) test is a simple and rapid microplate assay intended for the mass screening of milk samples. The amount of NAGase enzyme in milk is measured fluorometrically in the reaction between a substrate and milk (Kitchen et al, 1984). The NAGase activities of the milk samples being tested are compared with those of a milk standard. Interquarter differences are used to minimize the physiological variation among cows. The NAGase test may be more specific than some other tests because it detects the cellular damage during inflammation. Infection leads to the release of lysosome enzymes into the surroundings of the damaged cells. The procedures and equipment used to conduct the milk NAGase test are relatively simple and inexpensive. However, it has not received widespread adoption in North America.

Electrical Conductivity

Mastitic milk has a higher electrical conductivity (EC) than normal milk because of its higher electrolytic content, especially sodium and chloride ions. As a method of monitoring mastitis status, measuring EC is attractive. A conductivity sensor can be installed in the milk line to measure the EC of the milk from each quarter of each cow at every milking (Linzell and Peaker, 1975). A shift in electrolyte content in the milk is one of the earliest changes to occur with the development of mastitis. Therefore the automatic measurement of EC could be a useful early warning system.

Computerized milk EC monitoring systems are now available commercially for installation in milking parlors. Some difficulties have been encountered with the implementation of these system. Variations in the sensitivity and specificity of EC among herds have been reported as a considerable problem (Sheldrake, 1981). The use of a predetermined threshold of EC, without consideration of the differential conductivity between quarters, has led to diagnostic errors. It is important that the EC analysis be done on foremilk or stripping samples rather than during the main milk flow. Air bubbles in the milk can cause variations in EC results, and the electrodes can foul up because of milk and solids. However, with the development of protected in-line electrodes, and with the implementation of computerized data retrieval and analysis systems, the measurement of EC holds great potential for the automated monitoring of udder health. A summary of EC studies has been published (Nielen et al, 1992).

Hand-held conductivity meters, suitable for checking individual quarters, are now available. These devices give a digital readout of the EC result. This system represents an alternative to the CMT as a cowside diagnostic screening test.

Specific Antibody Test

Other than milk bacteriology, the diagnostic screening tests used in udder health management programs provide no indication of the causative bacterial agent. The recommendations for dealing with infected individual cows and for the specific components of an udder health management program depend somewhat on the predominant pathogen involved. Therefore it is important to have some method of specific bacterial identification. There is a great need for rapid, sensitive, and specific tests to identify microbial agents in milk samples directly. It is important that these tests can be conducted on preserved milk samples that have been collected for routine analytic purposes, such as DHI test day samples.

An enzyme-linked immunosorbent assay (ELISA) has been developed to detect the binding of *S. aureus* antibodies in milk to a purified antigen preparation (Adams, 1989). It has been shown that the shedding pattern of organisms in *S. aureus* infected quarters may be cyclic and, thus, periodically undetectable. A reported advantage of the *S. aureus* milk anti-

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body test is its ability to identify antibodies, even when the organisms may not be shed into the milk. The *S. aureus* antibody test and bacterial culture results have been compared (Gay and Fox, 1993; El-Rashidy et al, 1992). There were many false-positive results. The sensitivity and specificity of the test ranged from 59% to 93% and 89% to 100%, respectively. However, the use of milk bacteriology as a reference standard in this comparison may be inappropriate. Several DHIA laboratories have made this test available on samples already submitted for SCC and component testing. Systems need to be developed to use these results, in combination with SCC and milk bacteriology, for udder health management programs. Use of this technology has been outlined (Gay and Fox, 1993); in general, cows within 30 days of calving or with less than 30 lb of daily milk production should not be tested. If this system is to be used for identification of individually infected cows, then all cows should be tested at regular intervals. If a cow is test positive and is to be culled based on having an IMI caused by *S. aureus*, then confirmation of infection status should be done by bacterial culture of milk.

There is considerable difference in the cure rate of cows infected with different major mastitis organisms. It would be extremely useful to have rapid cowside screening tests to differentiate among these microorganisms. With rapid advancements being made in diagnostic methods through the use of biotechnology, such tests could be available in the near future.

Other Laboratory Tests

There are three other laboratory screening tests that have been evaluated for detecting mastitis (Emanuelson et al, 1987). Adenosine triphosphate can be extracted from milk and measured by light emission. Bovine serum albumin in milk can be determined by the radial immunodiffusion assay and measured by the diameter of a precipitation zone after 24 hours of incubation. The antitrypsin concentration in milk can be determined by a colorimetric procedure. All these tests can be used to determine the presence of udder infection. However, the potential for the large-scale use of these tests is most likely in combination with currently available screening procedures to increase the predictive value of the diagnostic process.

Summary

Because the vast majority of mastitis is subclinical, there is a great need for diagnostic screening tests to monitor the prevalence and incidence of IMI in an udder health management program. Many screening tests have been developed and tested. Milk bacteriologic tests are used as standard criteria. As new screening tests are developed and refined, individuals involved in dairy health management programs should be aware of the test performance characteristics and how they were evaluated.

CONTAGIOUS MASTITIS: GOALS, ASSESSMENT, AND CONTROL

Etiology

The contagious pathogens of primary concern in most dairies are *Str. agalactiae* and *S. aureus*, which are usually the predominant intramammary pathogens in herds with identified subclinical mastitis problems (bulk tank SCC routinely >500,000 cells/ml). SCCs average 900,000 to 2,240,000 cells/ml for quarters infected with *Str. agalactiae* and 1,500,000 to 1,820,000 cells/ml for quarters infected with *S. aureus* (Erskine et al, 1987b; Schultz, 1977). As a result, there is a strong correlation between herd SCCs and the number of infected cows in a herd. In herds with SCC ≥700,000 cells/ml, it is not unusual for at least 50% of the cows to be infected with these pathogens. Other pathogens, such as *C. bovis*, *Str. dysgalactia*, and *Arcanobacter pyogenes* are believed to have, at least in part, the infected udder as a reservoir for new infections. In addition, the contagious nature of *M. bovis* mastitis has been well described, and this pathogen has caused devastating mastitis outbreaks in some herds, particularly those that have expanded by addition of new animals into the herd. However, much of this section of the chapter will consider the identification and control of *Str. agalactiae* and *S. aureus* as the prototypical contagious pathogens.

Str. agalactiae is essentially an obligate udder pathogen (McDonald, 1977a). It spreads from cow to cow during milking, and it is typical for more than one quarter of an affected cow to be infected. Infections become chronic and remain for the most part in a subclinical state, with occasional, although rarely severe, clinical episodes. Colonization of the teat canal before invasion of the duct system of the gland is thought to be an important step in the initiation of infection. The best method to detect the presence of IMI caused by these organisms is by SCC screening and culture of milk samples from suspected quarters. Prevention of new infections must focus on procedures on the farm that are employed during milking of the cows. Elimination can often be achieved with treatment. Anecdotally, dairy managers who have experienced problems and subsequent resolution with *Str. agalactiae* mastitis note that cured quarters are softer and milk out quicker than when infected.

S. aureus also has a contagious reservoir of infection, and, as with *Str. agalactiae*, prevention focuses on milking procedures. *S. aureus* can colonize other tissues, particularly skin, thus there is more potential for other fomites of contamination than just milking equipment, such as milker's hands, or at times when teat skin is compromised after such trauma as cold-related chapping. *S. aureus* infections often result in deep-seated abscesses (McDonald, 1977a). Therapy is difficult, especially as resistance to antimicrobial drugs (particularly β-lactams) is more common as compared with streptococci (McDonald et al, 1976), and *S. aureus* may survive intracellularly following phagocytosis where antimicrobial concentrations are reduced. In addition, *S. aureus* has numerous extracellular substances that impart an ability to survive in the presence of a hostile host immune system. Consequently, elimination of infections by antimicrobial treatment is often not successful.

Goals

The goals of a contagious mastitis control program for a dairy are to produce and market the optimum amount of quality milk. Regulatory limits provide the framework for milk quality, but these limits do not promote optimum production of the cow and, as previously described, optimum profitability for the farm. Table 10-3 outlines reasonable goals for most dairy farms, realizing that because of differences among farm personnel and physical plant herd expectations can vary. In addition, it can be less profitable for the farm to blindly attempt to attain mastitis control goals at the expense of other aspects of the farm. An example would be the culling of genetically superior cows that produce a high volume of milk and detrimentally affect the cash flow of the farm. Culling to help reduce the prevalence of IMI in a herd is often used, but it should be done judiciously.

Assessment of Contagious Mastitis

The primary tools that determine the extent of contagious mastitis in a herd are SCC and bacteriology of milk samples.

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TABLE 10-3

Quality Milk Goals for Monitoring Contagious/Subclinical Mastitis

Goal	Level	Frequency of Monitoring
Bulk tank SCC*	<200,000 cells/ml	Monthly
Linear SCC distribution	<15% of the total herd: (1) ≥2nd lactation cows with linear ≥5 (2) 1st lactation cows withlinear SCC ≥4	Monthly
Standard plate count† (raw bacteria count)	<10,000 cfu/ml	Monthly
Preliminary incubation count‡	<20,000 cfu/ml	Monthly
Cows infected with *Streptococcus agalactiae* or *Staphylococcus aureus*	<1%	Quarterly if SCC goals are met, otherwise monthly
Residue violations	None	Every day

SCC, Somatic cell count.
*Bulk tank SCC can be misleadingly low if a high proportion of cows in a herd are out of the tank because of treatment-mastitis, or elevated if a few cows are contributing a disproportional level of somatic cells to the tank because of high SCC and production.
†May be caused by mastitis, poor udder preparation, improper cleaning, or inadequate refrigeration.
‡Not regulated by Pasteurized Milk Ordinance in United States; generally indicative of improper cleaning.

As indicators of inflammation in the mammary gland, individual cow SCCs serve as markers of potentially infected cows. They cannot be used to determine cause of infection but can help delineate cows to be cultured and thus promote more efficient time and money spent on bacteriology. In many herds, if herd bulk tank SCCs are meeting the goals of the farm and the percentage of cows with elevated SCC is low, little more action regarding the contagious mastitis program is required, except continued monitoring of monthly SCC. Occasional culture of milk samples from high SCC cows or the bulk tank may be warranted to monitor the presence of contagious IMI in a herd. If the quality milk goals are not being met for a herd, a logical place to start the investigation is to determine if contagious mastitis is part of the problem, and if so, the extent of the contribution that these pathogens have on the problem. It is best to first use SCC data to determine a plan of action for collecting milk samples for culture and provide information regarding risk factors associated with infection, such as lactation number, stage of lactation, and if examined retrospectively, the duration of the problem in the herd. Subsequent culture is then used to confirm or deny the presence of contagious pathogens in the herd and the prevalence of IMI. Typically, an SCC threshold of linear score 4 or 5 is used as the criterion for culture. If the focus of the plan is to identify cows infected with the contagious pathogens, veterinarians should collect composite samples, freeze them for at least 24 hours, and then culture. Follow-up sampling is indicated for negative isolation results and to confirm IMI caused by other chronic pathogens such as the environmental streptococci. For the example herd in Fig. 10-2, the herd average SCC is 782,000, and 19/41 cows (46%) have LS ≥5. It is apparent that the goals as suggested in Table 10-3 are not being achieved, and thus either the 19 cows with LS ≥5, or the 30 cows with chronic LS ≥4, could be selected for composite sampling for culture. Cow samples yielding no isolate in the laboratory should probably be cultured again.

Contagious Mastitis Control Programs

If it is determined from SCC information and subsequent culture that contagious pathogens are present in undesirable levels in the herd, the next step is to propose management protocols on the farm that will reduce the problem. To begin this process, a review and preferably direct observation of milking preparation and actual milking techniques is required. Particularly in herds with multiple personnel, and especially in herds with hired labor, it is important to understand that farm management protocol and actual milking time practices may not be the same. Review of critical areas such as udder preparation before milking, time of preparation and attachment of milking units, actual milking time, postmilking teat dipping, and dry cow treatment programs are essential. In herds with multiple milkers, the compliance of herd protocol must be established. This is also a good opportunity to review and/or perform an analysis of the operation of the milking equipment, including the ability to maintain a stable vacuum (effective reserve) and milk cows efficiently (pulsators, automatic take-off units, and replacement of liners and hoses). If marked behavioral changes or problems are noted in the cows during milking, stray voltage or harsh treatment of the animals should be considered. It is possible that the existing mastitis control program is sound, but because of unforeseen events such as

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addition of infected animals to the herd, or adverse changes in weather, the prevalence of IMI has increased to unacceptable levels. Nonetheless, to reduce the prevalence of infection in a herd we need to achieve three fundamental goals: **(1) prevent new infections, (2) eliminate existing infections, and (3) monitor progress after implementation, and if progress is not being made, seek alternative approaches in farm management.**

Prevention of New Infections

Postmilking Teat Dipping. Teat dipping with a germicidal solution immediately after every milking has proved to be an effective milking management practice to reduce the rate of new intramammary infections. Substantial evidence supports postmilking teat antisepsis as the single most effective practice in the prevention of new contagious IMI in lactating dairy cows. Teat dipping is a simple, effective, and economical means to reduce bacterial populations on teat skin. There is general agreement that the numbers and types of bacteria on teat skin have a direct relationship to the incidence and types of intramammary infections that develop in a herd. An effective teat dip, correctly used, can reduce the incidence of new udder infections by 50% to 90% (Pankey, 1984). Postmilking teat dipping must be done correctly and consistently. Proper teat dipping requires that teats are dipped with a clean solution immediately after milking and that teat ends and lateral surfaces are well covered. Sprayers are used in some milking parlors as an alternative to dipping in cups; however, there is a potential for improper coverage of teats with these devices, especially where labor is pressed to maintain cow flow through the parlor. If done properly, two to four L of dip are used for each cow in the herd each year. Herds with a high prevalence of infection despite an appropriate postmilking program may benefit from a change in teat dip germicides. Studies in Kentucky, Pennsylvania, and Michigan reported that the consistent use of some germicidal classes of teat dips may increase the prevalence of infection with contagious mastitis pathogens (Harmon et al, 1988; Erskine and Eberhart, 1991b; Erskine et al, 1998b).

The background information, regulations, classes of available products, proper storage and handling guidelines, application methods, and published efficacy data have been reviewed (Pankey, 1984). An updated listing of available postmilking and premilking products that have efficacy data published in peer-reviewed journals, is presented each year in the appendix of the Proceedings of the NMC. There are several major classes of postmilking teat germicides and many products available within each class. The products vary widely in composition, formulation, and mode of action. Each product should be evaluated for its safety, efficacy, advantages, and disadvantages. Caution should be exercised in selecting teat dips, and changes are not warranted in herds already achieving quality milk goals. Likewise, efficacy is best demonstrated in the prevention of naturally occurring IMI under field conditions, and the accepted protocol to evaluate this outcome is also presented in the NMC Proceedings. Because of wide variability in study design, practitioners are advised to carefully evaluate the validity of published studies to the approved protocol.

Teat dipping may promote healing of chapped skin. In one study, chapped teats dipped with a 1% iodophor—10% glycerin dip reduced *S. aureus* skin colonization and promoted faster healing than did undipped teats (Fox et al, 1991). In extreme cold, dipping should be practiced, but teats should be blot dried with paper towels before cows are exposed to the elements. Teat dips should be stored in a cool, dry place and not allowed to freeze. Contamination should be prevented and expiration dates observed. For economic reasons, producers are tempted to dilute commercially available products. However, their effectiveness and safety may not be maintained. At the end of milking, unused teat dip solution should not be poured back into the original container. Dipping devices should be cleaned regularly.

In summary, postmilking teat sanitization is an extremely important component of good milking management. The objectives are to kill mastitis pathogens residing on teat skin and reduce the rate of new intramammary infections. Teat dipping or spraying immediately after every milking should completely cover at least the lower half of each teat with a product of proven efficacy.

Premilking Hygiene and Udder Preparation. The effect of various approaches to premilking udder hygiene on the incidence of mastitis has been reviewed (Pankey, 1989). The major objective of premilking udder preparation and teat sanitation is to reduce the microbial population at the teat end. The aim is to minimize the probability of new IMI and have good milking performance (Galton et al, 1986b; Merrill et al, 1987). Milking time hygiene is extremely important because of the potential interaction between milking machine function and the microflora of teat skin. The incidence of IMI is highly correlated to the number of mastitis pathogens on the teat end at milking (Galton et al, 1988). however the effect on the prevention of new IMI with contagious pathogens is minimal compared with postmilking teat dipping.

There is considerable variation in premilking cow preparation, both in theory and practice. Alternative recommended procedures for premilking udder preparation include water hose washing and manual drying of teats, washing teats with a paper towel wetted in warm sanitized solution plus drying with a single-service paper towel, and using premilking teat dipping in germicide plus paper towel drying. It is argued that manual teat washing improves stimulation and the release of oxytocin for milk letdown in addition to cleaning debris from the teats and teat ends. In milking parlors in which hand-held spray washers are used, it is important to avoid wetting the udder. Excessive water use can lead to bacterial contamination of the teat cups. In addition, drop hoses in parlors have been cited in several case studies as sources of contamination and subsequent mastitis outbreaks caused by *Pseudomonas aeruginosa* (Erskine et al, 1987c). It is recommended that, unless cows are exceptionally dirty, water be avoided in the preparation of udders and teats for milking. In addition to individual paper or cloth towels, latex gloves should be used. Use of gloves may be particularly useful if the skin of milkers' hands is thought to play a role in herds with a high prevalence of *S. aureus* (culture of skin swabs compared with isolates from cows), or to protect milkers' hands from effects of germicides while milking.

Premilking teat disinfection with iodine-based teat dip preparations has become an increasingly common management procedure in North America. A survey of Ontario DHI producers reported that 12% used iodine predip (Gill et al, 1990). The use of predipping is expected to increase as mastitis problems shift from contagious pathogens to a predominance of infections caused by environmental organisms. There are only two controlled studies that have reported on the effectiveness of predipping (Galton et al, 1988; Pankey et al, 1987). In both these studies, there was significant merit in the use of iodine predipping for the reduction of udder infections caused by environmental pathogens but not contagious pathogens. Additional evidence is needed to evaluate predipping in a variety of management situations, in particular for the control of contagious pathogens.

Although premilking teat dipping with iodine-based germicides may play a role in reducing new intramammary in-

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fections, there are some precautions that should be taken. The major concern is the potential for increased iodine residues in milk. Galton et al (1986a) demonstrated that predipping with either 0.5% or 1% iodophor does not significantly increase milk iodine residues as long as a paper towel is used to dry the teats. Without drying, iodine residues were significantly increased. In addition, predipping in combination with postmilking teat disinfection may increase the potential for residue problems (Galton et al, 1984). There is a continuing search for germicidal products with naturally occurring ingredients and a wide margin of safety.

The overall objective of premilking sanitation is to have clean and dry teats ready for attachment of the milking equipment. Nonetheless, compared with a hygiene program that included postmilking teat dipping and total dry therapy only, Kingwill et al (1970) found no difference in decreasing prevalence of IMI as compared with a program that included (1) milkers wearing and sanitizing rubber gloves before milking of each cow, (2) use of a hypochlorite sanitizer in the udder wash water, and (3) use of individual udder wash cloths in addition to postmilking teat dipping and dry cow therapy. Concurrently, similar results were obtained in a study of 27 New York herds (Natzke, 1974). In 32 Pennsylvania herds, washing and drying of udders and the use of separate paper towels before milking were as frequently practiced in herds with high prevalence of contagious pathogens as those with low prevalence (Erskine et al, 1987b).

Thus substantial support exists for the combined use of postmilking teat dipping and total cow dry cow therapy (see later) as the most critical means of controlling contagious mastitis pathogens. Other hygienic practices, although possibly important in preventing infections caused by environmental, and to a lesser extent contagious, pathogens, or in achieving lower bacterial contamination of milk, have not been demonstrated to be as critical. Consequently, practitioners should emphasize to their clients the importance of postmilking teat dipping in the prevention of new contagious IMI.

Milking Equipment Attachment and Use. Oxytocin stimulation of mammary myoepithelial cells that surround the milk secreting alveolus is the primary mechanism of milk letdown, although teat stimulation on sympathetic tone in the mammary gland augments the oxytocin mechanism. Thus proper stimulation of the teats and udder to activate milk letdown is critical for achieving effective milk ejection during milking. Late lactation cows typically require more stimulus than early lactation cows (Reneau et al, 1995). Preparation of teats by cleaning and drying should take a minimum of 10 seconds, followed by a lag time before milking equipment attachment. Optimum prep-lag time (time between the beginning of teat preparation to the application of the milking machine) is accepted as 1 to 1.5 minutes in order to best use oxytocin-induced letdown (Rasmussen et al, 1992; Reneau et al, 1995). Prep-lag times greater than 3 minutes increase residual milk and decrease milk yields (Rasmussen et al, 1992). Implementing proper prep-lag times improves milk yield as well as decreases time of milking equipment attachment during milking (Reneau et al, 1995).

When attaching the teat cups, it is imperative to minimize the amount of air drawn into the system. Too large an air inlet could cause vacuum fluctuations that might generate milk aerosol impacts of the teat end and machine-induced infections. The machine position and support should be adjusted as necessary during milking. This ensures that the quarters milk out properly. The milking unit should hang on the cow as straight and level as possible. An improperly adjusted support could contribute to uneven milk out and to an unbalanced udder on some cows. In addition, there is an increased probability of liner slips (inadvertent air admitted into the system between the teat and liner) and squawking, which in turn increases the risk of new IMIs.

In a tie-stall barn, it is recommended that a maximum of three units per person be used. It is unlikely that milking with more than three units per person in a tie-stall barn is accompanied by the use of appropriate cow preparation and milking machine attachment methods. In more automated parlor systems the number of milkers needed per cow is highly variable, and cow throughput of the parlor is an overriding concern on many large dairies. The same care needs to be followed in preparing udders hygienically and efficiently in relation to the oxytocin "let-down"; however, cows are often prepared in shifts of five to ten cows at a time. Units are attached, and then the next group of cows is prepared.

A majority of milking machine-induced intramammary infections occur near the end of milking (Spencer, 1989). Liner slips occur with greater frequency near the end of milking. During a liner slip, small droplets of contaminated milk may be propelled back against the end of the other teats. Over a sustained period of time, liner slips and milk impacts may cause intramammary infection. Machine stripping is the act of putting hand pressure on the milker unit at the end of milking for the purpose of removing extra milk. It has been shown that machine stripping is habit-forming and eventually leads to increased milking time. In addition, there is a greatly increased risk of squawking, liner slips, and milk impacts during machine stripping.

As soon as a cow is milked out, the vacuum to the milker unit should be shut off and the teat cups removed (Griffin et al, 1982). The milker unit should gently fall off the teats, causing no irritation (Natzke et al, 1982). Removing the unit under vacuum causes milk and air to impact onto the teat ends (Spencer, 1989). Overmilking should be avoided to prevent teat end irritation. It is recommended that the unit be removed as soon as the first quarter is milked out. The risk of liner slip is also increased during overmilking. However, there is little evidence that overmilking causes an increased rate of IMI unless liner slips and teat end impacts occur. The practice of removing teat cups individually is also discouraged.

Establish Milking Order and Segregation Programs. In herds with a significant prevalence of contagious pathogens, such as *S. aureus*, establishing a specific milking order may be helpful to limit the rate of new infections. In general, first-lactation heifers and fresh cows should be milked first. Cows with a high SCC, chronic clinical mastitis, and current clinical cases should be milked last. The maintenance and management of both SCC and clinical mastitis records become important to make milking order programs work. This may be difficult to arrange in herds milking in parlors. In free stall housing, cows are usually grouped according to stage of lactation and production level. For nutritional management reasons, it is often suggested to have high-, medium-, and low-production groups. Fox and Hancock (1989) have compared the change in prevalence of coagulase-positive staphylococci in unsegregated herds to herds using a segregation program. The segregated herds did not control *S. aureus* any better than nonsegregated control herds. A more significant decrease in the prevalence of *S. aureus* mastitis was found in herds that gave priority to a full milking hygiene program in combination with dry cow therapy and culling. Segregation is not a simple, single solution to contagious mastitis problems.

Sanitize Teat Liners. Disinfection of the milking machine teat cup liners between cows has the potential of lim-

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iting the spread of contagious organisms from cow to cow. There is ample evidence that bacterial populations in liners can be greatly reduced by sanitization (Smith et al, 1985b). However, there is considerably less documentation that flushing liners causes a major reduction in contagious mastitis problems (Spencer, 1989).

In tie-stall milking barns, liner sanitization is a laborious process that involves dipping the claw in a series of solutions. Liners must be put through a rinse, a disinfectant, and another rinse to remove the germicide. The solutions should be kept hot and replaced when they become overly contaminated. Only two liners can be dipped at one time in order to avoid an air lock in the claw, which can reduce the effectiveness of the disinfection process. In large milking parlor operations, automatic backflushing of milking units between cows is commercially available. In conjunction with automatic takeoffs, the claw is flushed with rinse water, then disinfectant, then rinsed again, immediately after the unit detaches from the cow. Massive numbers of microorganisms can be removed from teat cups by this backflushing process (Smith et al, 1985b). However, documented reductions in new infection rates are limited. Further studies on the usefulness of backflushing are warranted.

Other Reservoirs of Infection. Conventional wisdom for *S. aureus* IMI states that the major source of new infections is the lactating cow, and that heifers should calve "clean" of contagious IMI because of lack of any exposure. However, reports have indicated that this should not be accepted as dogma for all herds. Although highly variable among geographic regions, reports indicate that as many as 2% to 50% of heifers may be infected with *S. aureus*, as well as other staphylococci, at calving before the first milking (Nickerson et al, 1995; Oliver et al, 1992; Pankey et al, 1991). "Summer mastitis," caused by *A. pyogenes*, has been reported in Europe as a significant mastitis problem related to fly bite dermatitis of the teats and ensuing infections (Madsen et al, 1991). Research from Louisiana has suggested that a similar mechanism may contribute to IMI caused by staphylococci, including *S. aureus* in heifers (Nickerson et al, 1995). In particular, the horn fly *Haematobia irritans* may serve as a vector in the transmission of *S. aureus*. Herds using some form of fly control had fewer cases of heifer mastitis caused by *S. aureus* and streptococci than did herds without fly control (Nickerson et al, 1995). In an elegant use of DNA fingerprinting, all of the *S. aureus* isolates collected from horn flies belonged to two subtypes identified in heifers with infections caused by the same pathogen (Gillespie et al, 1999). Thus, in herds with significant fly problems, the potential for primigravid or nulligravid heifers as a source of new infections should be considered. Treatment of quarters with an intramammary infusion before parturition decreased the prevalence of infection in heifers at calving (Oliver et al, 1992; Nickerson et al, 1995). Caution should be exercised before embarking on this protocol in most herds unless increased incidence of clinical mastitis, elevated SCC in early lactation, or preferably positive cultures of recently calved heifers is evident. The labor, risk of residues in milk, uncertainty of exact dates of calving, and the risk of IMI by breaching the teat end barrier demands careful herd record assessment before using this protocol.

In addition to insect sources, total eradication of *S. aureus* from a herd can also be limited by the potential exposure of cows from numerous other sources, including housing, feedstuffs, air, equipment, bedding, farm animals, workers, water, and skin (Roberson et al, 1994). Thus, although the primary source of infection for *S. aureus* is the udder of the cow, a careful understanding of the risk factors associated with new of IMI should be considered to alert investigators to other potential reservoirs of infection.

Vaccination. Development of vaccines for streptococcal mastitis has been slow to develop. However, there has been considerable effort to develop a vaccine against *S. aureus*. A good review of the subject is presented by Nickerson (Nickerson, 1999). Previous attempts to develop vaccines against cell wall components (protein A) and bacterial adhesion proteins (fibronectin-binding) have met with mixed results. However, new technology has developed a vaccine against the pseudocapsule that surrounds the bacterial cell wall when *S. aureus* grows in milk (Watson, 1990). The vaccine enhances antipseudocapsular antibodies that aid in opsonization of bacteria for phagocytosis by neutrophils. This approach, combined with α- and β-toxin antigens has demonstrated positive results in the prevention of subclinical IMI and clinical mastitis cases caused by this organism (Watson et al, 1996; Sears, 1990a; Nickerson et al, 1993). Commercial development has not as yet been provided, and eventual large scale efficacy trials would be needed to demonstrate long-term efficacy as well as economic feasibility. However, this concept is deserving of being pursued as a sound scientific method to prevent new *S. aureus* IMI.

Proper Installation, Function, Use, and Maintenance of Milking Equipment. The milking machine plays an integral role in the efficiency of the operation of a dairy farm, and it has direct contact with teat tissue. It must perform properly and consistently every day, year after year. For these reasons, it is important that the installation of the milking system be done according to approved guidelines. Regularly scheduled maintenance should be carried out and machine function evaluated by periodic analysis of the system. Each person involved in the milking management process should thoroughly understand the basic components, function, and operation of the milking equipment. They should also be aware of the significance of regular equipment maintenance and of the importance of good milking techniques.

In order to carry out the basic functions and achieve the objective of efficient removal of the milk with minimal opportunity for intramammary infection, milking and milk handling equipment requires three basic components: (1) a vacuum system, (2) a milk pipeline system, and (3) a bulk milk tank for milk cooling and storage. Fig. 10-3 shows a simplified schematic diagram of these three milking system components. A great deal of engineering expertise goes into the proper design, installation, and function of milking equipment. For the purposes of understanding the basic principles of machine milking, these three components are briefly described.

The proper functioning of milking equipment depends on the creation of a partial vacuum. A vacuum pump is used for this purpose. It continuously removes some of the air from the various lines in the milking system. The amount of air removed determines the system vacuum level, which is important for proper function. The vacuum level is monitored using a gauge that is read in kilopascals (kPa), millimeters of mercury (mm Hg), or inches of mercury (in Hg). If half of the air is removed from the system, the vacuum gauge would read 50 kPa (15 in Hg) vacuum. Vacuum pumps are rated on the basis of the volume of air they can move when the intake vacuum is at 50.7 kPa (15.0 in Hg). Cubic feet per minute (cfm) is the standard air flow measurement used. The cfm rating of a vacuum pump determines the number of milking units that can be used on the system. For example, in order to operate six units, the minimum vacuum pump capacity is 52 cfm.

Because the vacuum pump continuously removes a constant amount of air from the system, a vacuum reserve tank is placed between the pump and the vacuum supply line. The purpose of this tank is to provide a common site for connecting the vacuum header lines and to provide a reserve

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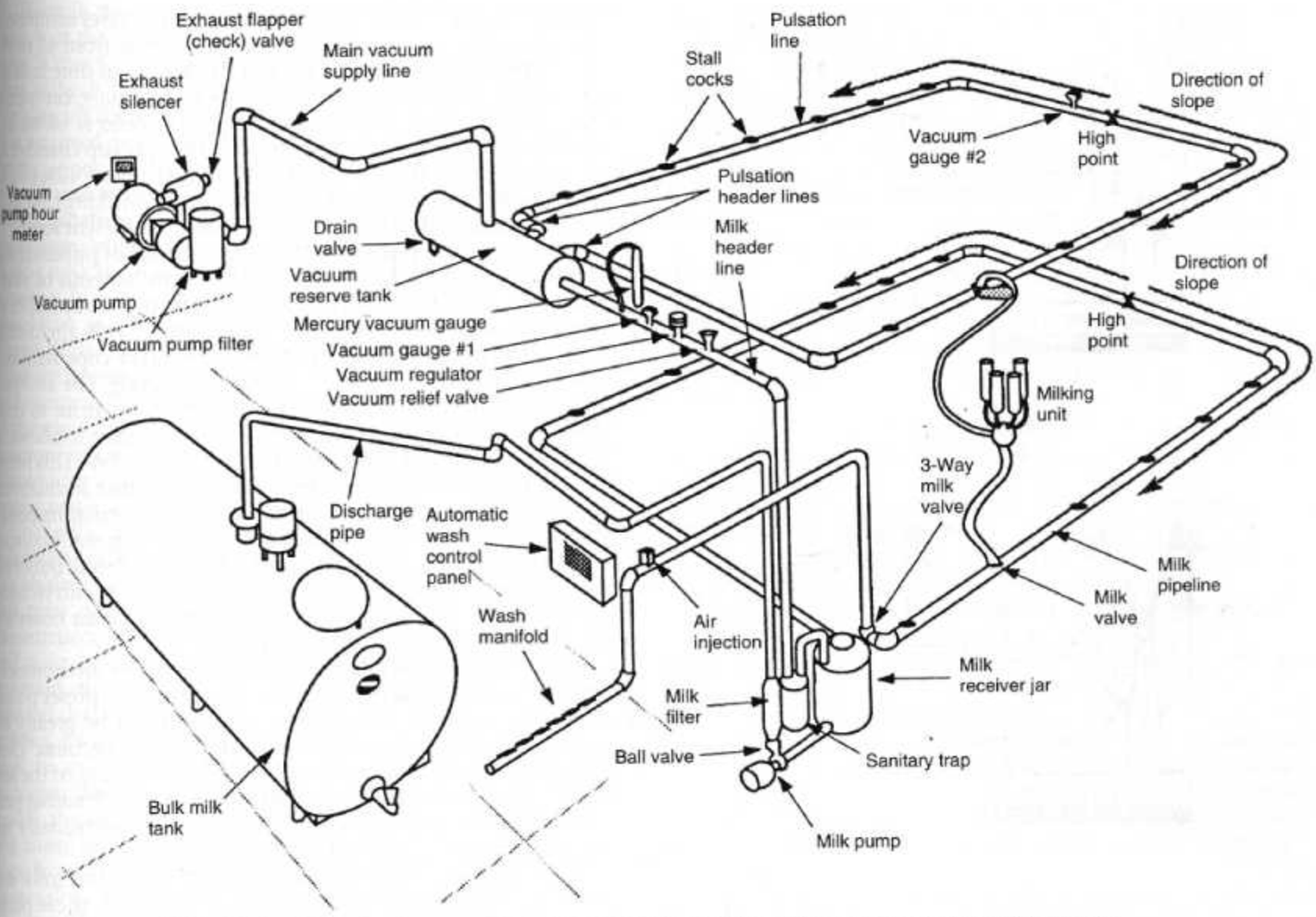

FIG. 10-3 Schematic diagram of the components of a milking system: the vacuum supply, the milk pipeline, and the bulk tank for milk storage.

of vacuum to help buffer the sudden admission of air into the system. For example, when a milking unit falls off a cow, there should be enough reserve vacuum to maintain system function. The amount of reserve vacuum needed in a system is a function of pump capacity, pump performance, regulator operation, and degree of system leakage. Vacuum reserve tanks are usually constructed of PVC plastic and should not be smaller than 75-L capacity. These provide a common site for connecting the vacuum header lines.

A vacuum regulator or controller is an important component of the vacuum system. The function of the regulator is to keep the vacuum of the milking system at a preset level by responding to changing air admissions into the system. The regulator should be located on the vacuum line between the sanitary trap and the vacuum reserve tank. The regulator should provide a rapid response to changes in vacuum. Servodiaphragm regulators are the most sensitive style available and are highly recommended. An increase in vacuum pump capacity cannot compensate for poor regulator function. Similarly, a sensitive regulator cannot compensate for a deficiency in pump capacity. The two components must work well together.

It is recommended that two vacuum gauges be installed in the system for the purpose of monitoring the system vacuum. One gauge should be located on the milking vacuum supply line, near the regulator. A second gauge is best situated at the far end of the vacuum pulsation line. A portable mercury monometer should be used on a regular basis to calibrate the accuracy of the system vacuum gauges and to make adjustments to the vacuum regulator. The preferred vacuum system installation consists of two header lines from the vacuum reserve tank that continue to form a completely looped pulsation line. The recommended vacuum lines are 76-mm (3-in) PVC pipe, adequately supported, slightly sloped in the direction of air flow, and with automatic drain valves. This line allows for attachment of the milking unit pulsators.

A properly functioning pulsation system is critical to teat and udder health. In addition, it should ensure fast, complete milk out. The pulsator causes the chamber between the teat cup shell and the liner to alternate regularly from vacuum to air source. Pulsators are electromagnetic or pneumatic. In an electromagnetic system, all pulsators function together off an electrical signal. An electronic control circuit turns the current to the electromagnet on and off. Pneumatic pulsators run off the vacuum system and use air to move a plunger or slide valve to cover and uncover the air passage, producing the pulsating action.

Understanding the dynamics within the teat cup and the characteristics of pulsation is crucial to ensuring that the objectives of mechanical milking are achieved. The chamber between the teat cup shell and the liner is regularly subjected to a vacuum source, whereas the inside of the liner is under a stable milking vacuum at all times. The dynamics of these changes are illustrated in Fig. 10-4. The pulsation cycle involves a milk phase and a rest or massage phase. When air is admitted between the shell and the liner, the liner collapses around the cow's teat. The collapsed liner has a massaging action on the teat and is called the *rest* or *massage phase*. Milk does not flow from the teat during this phase.

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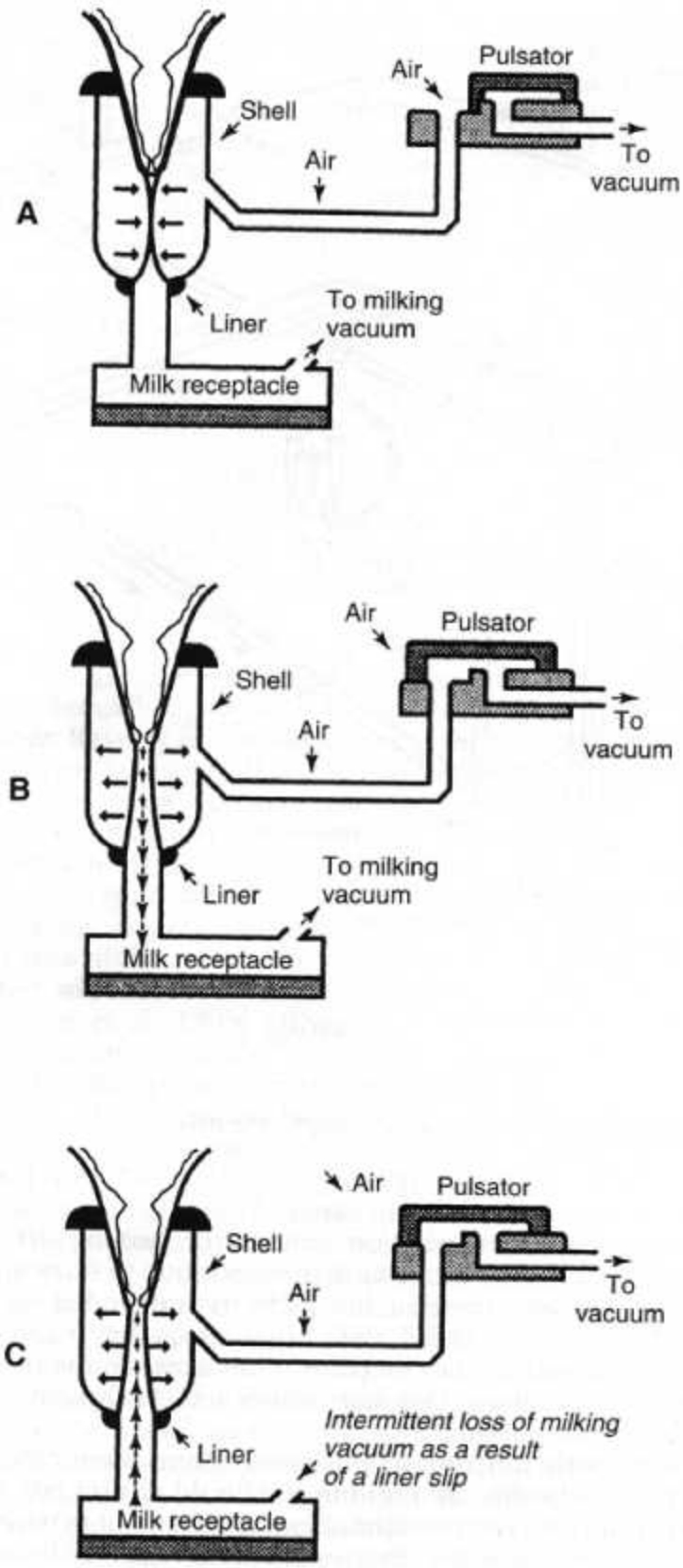

FIG. 10-4 Schematic diagram of the dynamics of pulsation and the changes within the teat cup of a milking unit during the rest phase and the milking phase, and in the event of a liner slip. **A**, Rest (massage) phase. **B**, Milk phase. **C**, Milk impact.

When the pulsator opens, the space between the liner and the shell is exposed to the system vacuum. This creates equal pressure on both sides of the liner, causing it to open. The cow's teat end is now exposed to the milking vacuum. This vacuum, in combination with the internal pressure of milk letdown within the cow's udder, causes milk to be drawn out through the teat streak canal. This component of pulsation is called the *milk phase*. The process of milking involves repeatedly opening (milk phase) and closing (rest phase) the teat cup liner.

The pulsation cycle is measured by the time, in seconds, for the completion of one milk phase and one rest phase. The pulsation rate refers to the number of cycles completed by a pulsator in 1 min. Pulsation rates range from 45 to 60 cycles/min. The pulsation ratio is the length of time in each cycle that the pulsator is in the milking phase compared with its rest phase. A common pulsation ratio is 60:40, indicating that in each pulsation cycle the teat cup chamber is milking 60% of the time and massaging the teat 40% of the time. Wide pulsation ratios can speed up milking time but can put undue stress on the teats from insufficient rest.

The pulsation phase refers to the method of pulsation for the whole milking unit, and is either simultaneous or alternating. In simultaneous pulsation, all four teat cups milk at the same time and rest at the same time. With alternating pulsation, two teat cups milk while two teat cups rest, and then alternate to complete the pulsation cycle. The alternating action may be from side to side or from front to rear. Alternating pulsation has several advantages. It allows a more uniform milk flow into and out of the claw. This helps minimize flooding of the claw, which can cause fluctuations in teat end vacuum. In addition, front-rear alternating pulsation allows for a wider pulsation ratio on the rear quarters, which encourages a more uniform and timely milk out of all four quarters. For alternating pulsation systems with two different ratios, care must be taken to ensure that air hoses are not reversed when attached to the claw.

Electromagnetic pulsators are unaffected by environmental temperature and can function at a constant preset pulsation rate and ratio. Pneumatic pulsators can be greatly affected by changes in temperature and system vacuum. They require more maintenance and constant checking of the settings. Thus electromagnetic pulsators using alternating pulsation are most commonly recommended, particularly for high-producing cows with fast milk letdown.

The problems of liner squawks, liner slips, and milk impacts were discussed. The dynamics involved in these problems are illustrated in Fig. 10-4. If a teat cup is not positioned properly on a teat, the liner may slip down the teat and produce a "squawking" sound. As this is happening, air is entering around the teat into the liner. The entrance of this air changes the system of stable milking vacuum within the claw and the other teat cups. These changes lead to droplets of milk being driven in a reverse direction back at the teat ends of the other teats, and these are referred to as "milk impacts." Repeated milk impacts, particularly with milk contaminated by mastitis pathogens, can cause new intramammary infections.

Milking parlors and stanchion barn pipelines have similar systems for transporting milk from the cow to the bulk tank. The components of the transport system are described in the direction of milk flow. The rubber or silicone insert in each teat cup is referred to as a liner, or inflation. The liner should milk cows safely, with a minimum number of squawks from downward slippage and without the teat cup crawl action of riding up on the teats to the base of the udder. Liner performance depends on many interrelated characteristics of the milking system. Narrow-bore liners are recommended. Liners must be compatible with the teat cup shell. The most important management consideration with respect to teat cup liners is to ensure regular replacement, as recommended by the manufacturer. As a general guideline, natural rubber liners last from 500 to 700 cow milkings, synthetic rubber liners from 1000 to 1200 cow milkings, and silicone liners from 5000 to 10,000 cow milkings. Other rubber parts of the unit, such as the short air tubes on the claw, should be checked constantly for cracks or signs of wear. These problems could seriously affect air flow and liner pulsation. Proper storage in dark, cool conditions, as well as the correct use of cleaners and sanitizers, can affect the life of rubber parts.

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The milk claw is an important component of the milking unit. It is the collection point for milk from the four teat cups. It should have adequate capacity to handle peak milk flow without flooding. Each claw should have a means of shutting off the vacuum to the teat end, so that the unit is not removed under vacuum. Most claws have an air vent in the upper half to allow a predetermined quantity of air into the unit to facilitate milk flow away from the cow and into the pipeline. Claws should be inspected routinely for cleanliness, plugged air vents, and dented liner connectors. A long milk hose is used to carry milk from the claw to the pipeline. It can be made of plastic, rubber, or silicone. It should be as short as possible, with an appropriate hose hanger. If the milk hose is crimped or allowed to loop, milk flows are interrupted and lead to irregular fluctuations in teat end vacuum. The milk hose should attach to an inlet located in the top third of the milk pipeline, at the 11 or 12 o'clock position. Inlets should be self draining and self closing and should not cause milk flow restrictions that would lead to irregular teat end vacuum fluctuations.

The milk pipeline serves two important functions. It transports milk from the cow to the receiver jar, and it carries air flow to provide milking vacuum to the teat end. Either glass or stainless steel can be used for milk pipeline construction. The milk line should form a complete circuit and must be supported rigidly from the floor in order to maintain the appropriate slope. It is generally recommended that milk lines be installed as low as is practical. In milking parlors, low pipelines are installed below udder level. In stall barns high pipelines are used but should be no higher than 2 m above the cow platform. Milk moves by gravity through the pipeline to the receiver jar. The milk line must be self-draining and should have a continuous slope from the high point toward the milk receiver jar. The correct slope is important for the movement of milk and air during milking as well as for proper cleaning of the system. In the construction of new tie-stall barns, it is recommended that the foundation, floor, and gutter be sloped toward the milk house end. This helps minimize pipeline height and ensures that the line slope facilitates drainage during milking and washing.

Line diameter is another important feature of milk pipeline design. In addition to line slope and the level of herd production, pipeline diameter determines the number of milking units that a system can handle. Too many units lead to milk line flooding and a reduction in air flow rate. Slugs of milk moving through the line is an obvious sign of milk line flooding. This problem has a negative impact on milking time, herd production, and udder health. The recommended minimum pipeline size (in inches) is the square root of the number of units milking into each slope. For example, for a 2-inch line, high-producing herds should not use more than four milking units per slope. Thus larger pipeline sizes are often recommended for new installations. Pipeline couplers or welds must prevent air leakage into the system.

Milk should flow into the receiver jar in a continuous, unimpeded fashion. When sufficient milk has accumulated, an electronic probe triggers the milk pump to transfer milk from the receiver jar to the bulk tank. A milk filter is inserted into the transfer system as a mechanism for removing coarse impurities that may have entered the line. The receiver jar is connected to the main vacuum supply. A device called a sanitary trap is used to separate the "air only" portion of the milking system from the "milk handling" side of the system. The sanitary trap is designed to protect the vacuum supply from potential damage caused by the chemical cleaning and sanitizing solutions used to clean milk pipelines.

A milking system should have the capability of measuring the amount of milk from each cow. In older milking parlor systems, weigh jars were often used for this purpose. They allowed for a quick, visual means of monitoring individual cow production at each milking, as well as providing vacuum stability to the cow. However, they were expensive and represented a challenge to clean. More recently, milk metering systems have been developed that give an electronic digital readout of the milk volume produced at each parlor station. These systems can often be adapted to automatic data recording in an on-farm computer system. In stall barn pipeline installations, several types of mechanical milk meters are in use. It is important that any metering system not be restrictive to the flow of air and milk. These restrictions can cause a drop in teat end vacuum and irregular, teat end vacuum fluctuations. Increased milking time, incomplete milk out, and new intramammary infections can result.

The bulk milk tank is the vessel used to cool and store raw milk until it is picked up by the bulk milk transport truck. All tanks must be of an approved sanitary design and construction. The cooling capabilities of bulk milk tanks are clearly specified. Appropriate cleaning and sanitizing procedures for bulk tanks are critical in order to prevent bacterial growth and contamination of raw milk.

Relationship of Milking Equipment to Udder Health. The milking machine can influence new IMI rates in several ways: (1) it may be a carrier of mastitis pathogens from one cow to the next, (2) it may serve as a pathway of cross infection within cows, (3) malfunctioning or improperly used equipment may fail to relieve congestion in teat tissue, with eventual teat end damage and IMI occurring, and (4) abrupt loss of milking vacuum may create changes in air movement of sufficient force to move pathogens past the streak canal defenses. This phenomenon is known as the *impact mechanism*.

The pathogenesis of new infections related to machine milking probably involves all four of these factors (Spencer, 1989). However, even though the milking system becomes the focus of many herd udder health investigations, there is little evidence that machine factors are of primary importance in most problem herds. It has been difficult to link milking machine factors and prevalence of herd infection (O'Shea et al, 1979). Mastitis has been difficult to produce experimentally by altering machine function (Olney and Mitchell, 1983). In a study of several problem herds with pipeline milking systems, only 6.6% of the infections could be attributed to the milking machine (Schmidt-Madsen and Klastrup, 1980). In a Pennsylvania study, operation or maintenance of milking equipment did not differ between herds with a high or low prevalence of contagious mastitis (Erskine et al, 1987b).

A great deal of research has been directed toward the identification of machine factors related to mastitis. Although many problems have been identified, the only factors consistently associated with udder health problems are pulsation failure and the impact mechanism related to the inability to maintain a stable vacuum level at the teat end. Appropriate pulsation is important for sufficient teat end massage. Although a continuous vacuum removes milk from cows' teats, it eventually causes excessive congestion, edema, and teat end damage. An adequate compressive load by the liner on the teat tissue is necessary to relieve the congestion. Mechanical failure of the pulsator, shortness of the liner barrel, or a liner rest phase that is too short are the most common examples of pulsation problems. The impact mechanism results from an abrupt loss of milking vacuum. Poor liner design, inadvertent air leaked into the system such as when a unit is kicked off an udder or leaks in the pipelines, or inadequate effective reserve air flow of the system (the amount of air that can be admitted without a drop in vac-

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uum) from improper pump or regulator function, can all contribute to vacuum fluctuations.

Summary of New IMI Prevention. The prevention of new IMI caused by contagious pathogens often focuses on lactating cows, and the events that occur immediately before, after, and during milking. Postmilking teat dipping is the most critical event that occurs during this part of a cow's daily routine. On an individual herd basis, other problems such as contamination on milkers' hands, teat end trauma, careless preparation, and potential machine problems can contribute; however, these are not usually major risk factors in the prevention of new IMI caused by contagious pathogens, and it is important to maintain a perspective of any management practice of mastitis prevention in relation to all others.

Elimination of Contagious Intramammary Infection

Elimination of IMI During Lactation. Subclinical mastitis does not present an urgent potential loss of gland function or life to the cow. Therefore therapy is administered on the premise that treatment costs will be outweighed by compensatory production gains after elimination of infection. In the case of contagious pathogens, elimination of infection may also cause decreased risk of new infections in previously noninfected cows. Although host immune defenses play a critical role, the degree of therapeutic success in treating subclinical mastitis relies predominantly on the type of causative pathogen, and often not on the drug regimen selected. Most often the predominant pathogens causing subclinical mastitis are streptococci and staphylococci. In particular the contagious pathogens *Str. agalactiae* and *S. aureus* offer a study in opposites with respect to therapeutic success.

Prevalence of *Str. agalactiae* IMI can be reduced rapidly by "blitz" treatment. With this method an entire herd, or more economically, all the culture-positive cows in a herd, are treated with antimicrobials. The most efficacious and cost-effective regimen is to use intramammary β-lactam therapy, although use of erythromycin has been successful. All four quarters of infected cows should be treated to ensure elimination of the pathogen from the cow and prevent possible within cow cross-infection of a noninfected quarter by an infected quarter. Cure rates can often be from 75% to 90% and are economically beneficial (Weaver et al, 1986; Erskine and Eberhart, 1990; Erskine et al, 1996). Commercial intramammary products are as efficacious as procaine penicillin G infusions, and thus these products are preferred because of higher quality control for sterility and better reliability for predicting withholding periods for milk and meat discard after treatment (Weaver et al, 1986). Much of this success relies on the high degree of antimicrobial susceptibility of *S. agalactiae,* as well as it being essentially an obligate udder pathogen. It is necessary to monitor treated herds by SCC and bacteriology to further identify and treat cows that were not identified as being infected initially. Usually, 30-day monitoring intervals after each treatment are adequate. A small percentage of cows will not respond to therapy and are best segregated or culled. In addition, failure to use postmilking teat dipping and total dry cow treatment to prevent new IMI while eliminating existing IMI from blitz treatment will ultimately cause considerable expense and frustration on the part of the producer because of subsequent reinfection of treated cows. Parenteral therapy is not likely to offer any benefit over intramammary therapy, and in one study, 90% cure rates were achieved with intramammary penicillin-novobiocin therapy as opposed to 9% with intramuscular ceftiofur, an elegant demonstration as to the importance of pharmacokinetics for parenteral drug selection (Erskine et al, 1996).

Other common streptococci causing IMI are *Streptococcus dysgalactiae, Str. bovis,* and *Str. uberis*. As with *Str. agalactiae,* most of these streptococci are very sensitive in vitro to antibiotics, especially penicillin. In one study, virtually 100% of *Str. uberis, Str. dysgalactiae, Str. bovis,* and group G isolates were sensitive to penicillin, although only 63% of the enterococci were sensitive to penicillin (McDonald et al, 1976). Despite this apparent sensitivity however, these streptococcal infections are not as easily cured as those caused by *Str. agalactiae.* Controlled clinical data on the therapy of streptococcal infections is not extensive. Intramammary administration of β-lactams is considered to be effective therapy. However, efficacy and cost-effectiveness of this therapeutic regimen is difficult to assess. In strains with in vitro susceptibility to a combination of penicillin and novobiocin, intramammary therapy has obtained cure rates of 90% or more for subclinical IMI caused by *Str. agalactiae, Str. uberis,* and *Str. dysgalactiae,* and 77% for other streptococci (Owens, 1997)

Studies of treatment efficacy of *S. aureus* mastitis have found cure rates of 25% to 55% of infected quarters in experimental infections that were evaluated for 21 to 60 days after infection (Newbould, 1974; Owens et al, 1988). However, natural infections are usually of longer duration before therapeutic intervention is used and thus more refractile to therapy. Intramammary cefoperazone for the treatment of clinical *S. aureus* mastitis led to bacteriologic cures for only 39% of the cases, as measured 14 days after treatment (Wilson et al, 1986). These results may be optimistic since assessment of bacteriologic cures depends on the time period the infection is monitored after therapy; apparent cures often relapse as time after treatment increases, especially if assessed before 30 days (Newbould, 1974).

Consequently, novel combinations of drugs, including parenteral treatment regimens, may be needed to eliminate a higher proportion of infections. In experimental infections in lactating cows, the combined use of intramuscular procaine penicillin G and intramammary amoxicillin achieved a better cure rate (18/35 infected quarters) than did intramammary amoxicillin alone (10/40 infected quarters (Owens et al, 1988). Parenteral administration as an adjunct to intramammary therapy has been further supported by an additional study that determined improved cure rates for lactating cows with *S. aureus* IMI when they received 10 mg/kg body weight of oxytetracycline in addition to intramammary antimicrobials as compared with cows administered intramammary infusions only (Sol et al, 1990). In addition, therapy that is administered for longer periods than those typical for labeled intramammary regimens (4 as opposed to 2 days) maintains MIC in the gland for more effective time periods and causes better efficacy (Ziv et al, 1981).

Therefore therapy of chronic, subclinical IMI may have the best probability of success by including parenteral, in addition to intramammary, therapy; preferentially it should be administered for periods long enough to insure drug levels above MIC to allow effective killing of the pathogen. However, cure rates attained may not be much better than those attained from spontaneous cure. In addition, definitions of cure must be made critically, and affected quarters monitored bacteriologically for at least 30 days to encompass the refractory period when IMI is present but bacteria may not be isolated.

With the exception of *Str. agalactiae,* antimicrobial therapy is not recommended for subclinical IMI in lactating cows. Exemptions exist, but other alternatives should be explored first. The most attractive alternatives are therapy of dry cows and culling.

Elimination of IMI During the Dry Period. The dry period offers a valuable opportunity to eliminate IMI while cows are not lactating. Thus the expense of discarded milk

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after therapy can be avoided, and with proper identification and segregation of dry cows out of the lactating herd, residues in marketed milk can be averted. In addition, once involution occurs 1 to 2 weeks after dryoff, the host defenses of the mammary gland become markedly more effective in eliminating IMI. This is in part due to increased phagocyte efficiency; increased involvement of lymphocytes and macrophages; elevated concentrations of lactoferrin, complement, and immunoglobulin; and the presence of a keratin barrier in the streak canal of the teat (Nickerson, 1989a). Furthermore, the beginning and the end of the dry period represent times of increased risk of infection (Eberhart, 1986). The greatest increase in susceptibility is during the first 3 weeks of the dry period. In this period the new infection rate is many times higher than during the preceding lactation as a whole. A second period of heightened susceptibility occurs just before parturition (Fig. 10-5). The average rate of new infections in untreated dry cows is expected to be between 8% and 12% of quarters (Eberhart, 1986). The objective of udder health management during the dry period is to have as few infected quarters as possible at calving. Thus infections present at the time of drying off should be eliminated, and the rate of new intramammary infections during the dry period must be minimized.

Although the focus of mastitis control schemes for the dry period is often on contagious pathogens, environmental bacteria need to be considered. Exposure to environmental pathogens is likely to continue throughout the dry period. Thus the prevention of new dry period infection with environmental agents represents a considerably greater challenge (Eberhart, 1986). Herds that have implemented a basic mastitis control program still need to be aware of the importance of preventing environmental infections in the dry period. There are different rates of infection by the various environmental agents as the dry period progresses (Smith, 1985b,c). For example, infections with environmental streptococcal species, *Klebsiella* sp., and *Enterobacter* sp. occur more frequently early in the dry period. *E. coli* infections tend to occur immediately before calving. Dry cow management strategies need to account for the risk of infection during the entire period from last milking until the next calving. In addition, the cessation of milking time hygienic practices, such as teat dipping, allows bacterial subpopulations on teat skin to increase. It has been shown that *S. aureus* numbers are high immediately after drying off.

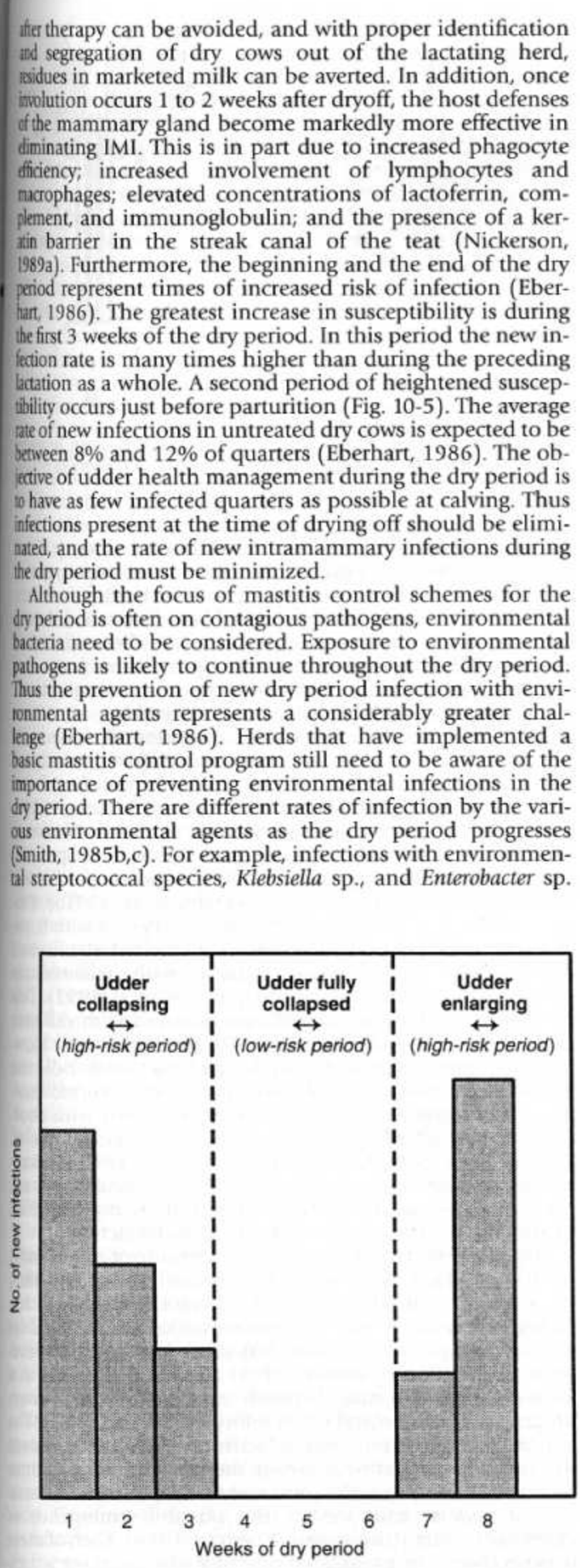

FIG. 10-5 Graphic representation of the frequency distribution of new intramammary infections in dry cows showing the periods of high and low risk.

Early research in 14 herds in England (Dodd et al, 1969) determined that although teat dipping reduced the new infection rate by 50% over a period of 12 months, the prevalence of all IMI decreased by only 14%. Antimicrobial therapy of all dry cows at the end of lactation was proposed to eliminate existing infections; such therapy was proved to be an effective complement to postmilking teat dipping. Subsequently, many studies have supported the combined use of postmilking teat dipping and total dry cow therapy (therapy of all quarters of all cows at the start of the dry period) as an effective management practice for controlling contagious mastitis (Erskine et al, 1987b; Oliver, 1984). Dry cow therapy has become the most effective and widely used mastitis control method for dry cows. Its efficacy and advantages are well known (Eberhart, 1986). Particularly for streptococcal IMI and coagulase-negative staphylococcal IMI, cure rates are often near 90%. However, the elimination of chronic IMI such as that caused by *S. aureus* or *Str. uberis* is less successful. Dry cow therapy also reduces the incidence of new intramammary infections by 50% to 75%.

Long-acting antibiotic preparations have been formulated specifically to treat subclinical mastitis and to prevent new infections in dry cows. These preparations include drugs that target the therapy of gram-positive pathogens such as benzathine cephapirin, benzathine cloxacillin, and sustained-release formulations of erythromycin, novobiocin, and penicillin. The withholding period for milk from animals treated with these dry cow formulations ranges from 30 to 42 days after treatment. The label directions must be followed carefully for the recommended dosage level, required withdrawal period, storage guidelines, and expiration dates. A general recommendation is that dry cow treatment should never be administered within 1 month of the expected calving date, and if therapy in this time period is necessary, products designed for lactating cows are recommended. Single-dose syringe preparations of dry cow antibiotic treatment are recommended. The risk of contamination by environmental bacteria and yeast is much higher for multiple-dose bottles than for single-dose syringes.

Intramammary infusion is a highly used and widely recommended procedure for mastitis therapy. However, there is a potential for the introduction of organisms during the infusion process. Unsanitary infusion practices can introduce antibiotic-resistant environmental organisms into the udder. Infection with opportunistic microorganisms, such as yeast or *Nocardia* sp., may cause more extensive udder damage than the original organism for which treatment was being administered. Adequate teat end preparation and careful dry cow treatment procedures can reduce this risk. Dry cow treatment procedures should be carried out as follows: (1) milk out the udder completely, (2) immediately after teat cup removal, dip all teats in an effective teat dip, (3) allow the teat dip to dry (if necessary, remove excess dip from teat ends with a clean, single-service paper towel), (4) disinfect each teat end by scrubbing for a few seconds with a separate alcohol-soaked cotton swab (start with the teats on the far side of the udder and work to the near side, allowing the alcohol to dry), (5) infuse each quarter with a single-dose syringe of a recommended dry cow treatment, starting with the teats on the near side of the udder, and (6) dip all teats in an effective teat dip immediately after treatment.

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The necessity of using appropriate dry cow treatment procedures cannot be overemphasized. The importance of these procedures has been demonstrated vividly with reports of udder health problems across Canada. From 1987 to 1989, a dramatic increase in the rate of isolation of *Nocardia* sp. from milk samples submitted to diagnostic laboratories was documented (Dohoo and Leslie, 1991). Three separate case-control studies were conducted to determine risk factors associated with this increase in *Nocardia* mastitis (Stark and Anderson, 1990; Ollis et al, 1991; Ferns et al, 1991). Each of these studies reported that blanket dry cow therapy, especially with neomycin-containing products, was an important risk factor for the occurrence of *Nocardia* mastitis. However, *Nocardia* organisms were not found as a contaminant of the suspected products. In one study, teat end preparation by scrubbing with an alcohol-soaked cotton swab protected against the occurrence of *Nocardia* infection when teats were contaminated experimentally with organisms immediately before drying off (Leslie et al, 1992). Most commercial dry cow treatment products provide individually wrapped alcohol-soaked cotton swabs for use with each syringe. The use of good teat end preparation before intramammary infusion needs to be emphasized continually to clients, and periodic comparisons of the number of alcohol pads in a box of mastitis infusion tubes with the number of tubes may offer insight as to teat end preparation compliance.

The problem of new dry period infections associated with the method of treatment has been the subject of some investigation. Partial insertion of the infusion cannula (up to 4 mm) has caused fewer new intramammary infections and improved cure rates (Boddie and Nickerson, 1986). The improvement with a short cannula is attributed to fewer organisms being delivered beyond the streak canal. In addition, antibiotic that is deposited within the streak canal should control local infections. Major pharmaceutical companies have developed modified infusion cannulas for the convenient use of a partial insertion method of administration. These devices are now widely available on commercial dry cow products. The difference between full and partial insertion of the infusion cannula is illustrated in Fig. 10-6.

Thus dry cow therapy is a critical part of a contagious mastitis control program. The major benefits are prevention of new IMI during the dry period and elimination of existing IMI. As a result of enhanced host defenses in the mammary gland, success of therapy is more likely for many pathogens during the dry period than during lactation. Nonetheless, infections caused by *S. aureus* can be the prototypical therapeutic problem in the elimination of IMI in many dairy herds. Bramley and Dodd (1984) stated that "one of the major limitations to effectiveness of mastitis therapy was the poor response of staphylococcal infections." In a retrospective study, new infection rate during the dry period of *S. aureus* in quarters was 11% when treated with one of three commercially available intramammary infusion products containing (1) cloxacillin, (2) neomycin and cloxacillin, or (3) a combination of nafcillin, procaine penicillin, and dihydrostreptomycin as compared with 4.9% in nontreated control quarters (Ziv et al, 1990). Dry cows administered intramammary cephapirin benzathine had a cure rate of 30.8%, and a new IMI rate of 51.7%, as compared with 33.3% and 29.3% in untreated quarters (Soback et al, 1990). However, subcutaneous norfloxacin nicotinate administered at the start of the dry period achieved a better cure rate (66.6%) and lower new infection rate over the dry period (17.1%).

The studies just mentioned provide evidence that herds with *S. aureus* IMI that are difficult to eliminate may want to consider including systemic drug regimens, preferably antimicrobials that distribute well in mammary tissue and abscesses

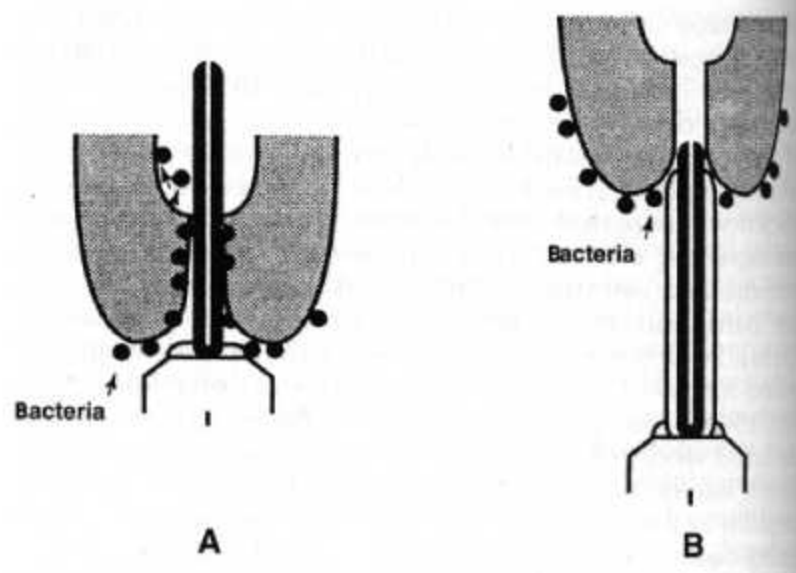

FIG. 10-6 Diagrammatic representation of the difference between **A,** full insertion and, **B,** partial insertion of the infusion cannula during intramammary therapy.

(e.g., tetracyclines, macrolides, and fluoroquinolones). Alternatively, the most effective therapy of chronic, nonresponsive *S. aureus* IMI may be to cull the cow from the herd.

Numerous cytokines, which regulate cell function during immune and inflammatory processes, have been identified and purified from cattle. With subsequent identification of the genes responsible for cytokine synthesis, recombinant production has been made possible. Cytokines that have demonstrated promise for use in the prevention or treatment of bovine mastitis are interleukin-1 (IL-1) and interleukin-2 (IL-2), interferons, and colony stimulating factor (Sordillo et al, 1991; Daley et al, 1992, Nickerson, 1989b, Oliver et al, 1990b). Intramammary IL-1β and IL-2 increase mammary gland polymorphonuclear leukocyte diapedesis. In addition, IL-2 activates inducible superoxide production and phagocytosis in neutrophils (Daley et al, 1991b). Preliminary trials with cows experimentally infected with *S. aureus* determined that 38% and 42% of infected glands were cured when treated intracisternally with recombinant bovine IL-1β and IL-2, respectively (Daley et al, 1992). This compared similarly with cure rates achieved with different intramammary formulations of sodium cephapirin. However, two subsequent field trials determined that IL-2 did not markedly improve cure rates among *S. aureus* infected quarters, and in one trial use of IL-2 was associated with abortions in treated cows (Hogan et al, 1995; Erskine et al, 1998a). Thus cytokines modulate and even enhance nonspecific cellular defenses, although clinical availability is not yet a reality; as yet, we do not understand the repercussions of altering the many mechanisms of cytokine activity.

Although dry cow therapy is a cornerstone of any mastitis control program, there is continuing controversy regarding the need to treat all quarters of all cows. This debate has gained momentum as the implementation of basic udder health management practices has caused a reduced prevalence of infection (Schultze, 1983) and an association in a large observational study between selective dry cow therapy programs and improved profitability (Gill et al, 1990). The major reasons for pursuing selective therapy are to reduce the expense of treatment, avoid the elimination of minor pathogens that may make cows more susceptible to environmental agents, and prevent the possible emergence of antibiotic-resistant organisms (Eberhart, 1986). Each of these reasons should be considered carefully when making a decision between selective and total dry cow therapy.

An important prerequisite for the large-scale implementation of selective dry cow therapy would be the develop-

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ment of a cheap, practical, sensitive, and specific test to identify infected cows. The positive and negative predictive values of any of the available screening tests are unacceptable as a basis for decisions concerning selective therapy. The history of clinical mastitis, CMT, individual cow SCC, and even bacteriologic culture all leave some infected cows untreated. In addition, many uninfected cows are treated. To compensate for the inadequate predictive values, repeated cultures would be necessary to enhance detection of infected cows. This would offset the benefit of decreased labor and product cost gained by selective therapy. It also must be considered that the prevention of new intramammary infections is effectively lost with the selective approach. Natzke (1981) has estimated that total dry cow therapy reduces new infection rates from approximately 14% to 7% of quarters. The increase in milk production from preventing these infections is sufficient by itself to offset the cost of antibiotic treatment for all cows. Currently, it is clear that the replacement of complete dry cow therapy with a selective program cannot be justified economically.

Total dry cow therapy can reduce the prevalence of infection with both major and minor udder pathogens. It has been suggested that the reduction of these minor infections is associated with an increase in clinical mastitis. One large epidemiological study did not support this hypothesis (Schukken et al, 1989a). The study followed 125 farms with low bulk milk SCC. Dry cow treatment had neither a beneficial nor a detrimental effect on the rate of clinical mastitis during lactation. Environmental conditions and individual cow factors were the most important risk factors. It would appear far more useful to develop meaningful programs to prevent environmental infections than to debate the risk of having a low herd SCC.

Despite blanket dry cow therapy, some cows calve with infected quarters and some with clinical mastitis. Several risk factors affecting the results of dry cow treatment of *S. aureus* IMI have been evaluated (Newbould, 1974; Sol et al, 1990). Probably the single most important factor in predicting the success of therapy is the duration of infection. Infections that have been present for greater than 2 to 3 months are less likely to be treated successfully than more recent IMI. Quarters of cows that have three or four quarters infected have a poor cure rate; this may reflect an inherent susceptibility of the affected cow to infection. As the age of the cow increases, the probability of *S. aureus* infections being cured by dry cow therapy decreases; this also could reflect duration of infection. In addition, the cure rate of *S. aureus*–infected quarters diminishes as the SCC before treatment increases. Controlling for age and number of quarters infected, there was a significantly lower cure rate in quarters with a SCC of greater than 1×10^6 cell/ml (Sol et al, 1990). There is a distinct herd effect on the success of dry cow therapy. The cure rate of *S. aureus* has been shown to be higher in herds with good hygiene and with a low prevalence of *S. aureus* infections at drying off (Sol et al, 1990).

Thus there is considerable potential in using individual cow and herd-level information to predict the likelihood of a *S. aureus* IMI cure. For example, an older cow with three infected quarters and a persistently high SCC has a low probability of a cure. Remember that antimicrobials only help the immune system in clearing IMI, and that signs of immune compromise such as multiple quarters infected should be used as signals that individual cows are poor therapeutic risks. Continued development of information management systems to assist with therapy and culling decisions can clarify the expectations of dry cow treatment.

Persistent *S. aureus* infections represent only one of the shortcomings of antibiotic treatment for dry cows. Most dry cow products are formulated for efficacy against gram-positive cocci. These antibiotics are of limited usefulness against gram-negative bacteria. In other words, new coliform infections would not be prevented by this therapy. Even though dry cow products are formulated for sustained activity, the provision of adequate protection during the critical prepartum period is questionable (Smith, 1985c). The persistence of effective levels of antibiotic has been evaluated for various dry cow treatments (Oliver et al, 1990a). Few products have persistent activity until the time of calving. One potential solution for protection through the critical periparturient period is the infusion of a lactating cow product 1 to 3 days prepartum (Pankey et al, 1982a,b). This approach merits investigation. However, there are concerns about the predictability of calving, accuracy of predicted calving dates, and the potential for antibiotic residues in milk of cows that calve early.

Appropriate dry cow management is extremely important for the maintenance of optimum udder health. Antibiotic therapy at the end of lactation is the most effective method of eliminating existing infections. Dry cow therapy also significantly reduces the rate of new infections during the dry period. Until better diagnostic tests and data management methods are available, the preferred approach is a blanket dry cow therapy program. This involves the treatment of all quarters of all cows immediately after the last milking. In addition, provision of a clean, dry environment and a properly balanced ration assists in the prevention of new dry period infections. Better methods of enhancing mammary involution and protecting the teat end need to be developed. Special attention is required in the precalving period.

Elimination of Infections by Culling. Culling may be the most effective method of decreasing the prevalence of chronically infected cows. The ability to cull infected cows is often limited by the need to maintain ample marketed milk for farm cash flow. Culling must be done judiciously with respect to production, breeding performance, genetic potential, and other health problems. Excessive culling to achieve quality milk premiums might have a negative net financial impact on herds. An alternative to culling chronic cows is to chemically dry off an infected quarter. Two to three doses of 60 ml of Novalsan solution (2% chlorhexidine acetate) has been reported to enhance fibrosis and involution of the treated gland (Boddie and Nickerson, 1994). The success of achieving fibrosis is variable and, if effective, permanent. This may allow the continued milking of a genetically superior cow, and compensatory milk production with the noninfected quarters is likely to maintain near normal; production levels. This would not be a good choice for cows with multiple infected quarters.

Frequently, dairy producers want to determine if culling a cow or multiple animals from a herd to lower the herd average SCC is a beneficial economic decision. As discussed with the example of the DHI reports (Fig. 10-2), there are many factors that enter into this decision. However, one of the incentives that is often discussed is the potential benefit from bonuses that are applied to lower herd SCC levels. A worksheet that reviews potential scenarios regarding this process is presented in Chapter Appendix B.

Mycoplasma Mastitis. Mastitis caused by *Mycoplasma bovis* and closely related pathogens has been increasing in importance throughout the dairy industry. Greater risk is associated with increasing herd size, especially if expansion involves purchase of cattle from varied sources. Explosive herd outbreaks of clinical mastitis may occur, or sporadic episodes in a few cattle at any point in time. As with other contagious pathogens, the primary reservoir of infection is believed to be other infected cows and subsequent exposure in the milking equipment. However, unlike the other typical contagious pathogens, *M. bovis* is believed to be able to

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cause an IMI from a hematogenous route following a respiratory infection (Jasper, 1982). Arthritis is also a common result of cows with bacteremia. Calves in affected herds may display respiratory symptoms and head tilts associated with inner ear infections. It has been suggested that milk from infected cows may be a source of infection for young calves, which in turn may display respiratory signs or become asymptomatic carriers (Walz et al, 1997). Reports from New York and Ohio determined that 2% to 3% of herds had *Mycoplasma* spp. in the bulk tank, although a California study isolated this organism from nearly 50% of the herds surveyed (Gonzalez et al, 1992; Hoblet and Muzammil, 1996).

Clinically, cows with IMI caused by *M. bovis* can be latent carriers or display clinical mastitis, although SCCs are usually consistently elevated. Initial episodes of clinical mastitis for an individual cow are often acute; systemic involvement can occur and often affect multiple quarters, which is unusual for other pathogens. Affected quarters often have serous secretions, and may go agalactic within a matter of days. Because of the more stringent culture requirements of these organisms compared with more common aerobic pathogens, it is best to involve diagnostic laboratory assistance to isolate this organism from milk samples of suspect cows. One of the more important methods of control is to identify and segregate infected cows. Affected cows, especially those that chronically display systemic signs or do not recover milk production, should probably be culled. A report from Florida suggested that many cows will return to adequate productivity, and thus culling should be made on an individual basis (Brown et al, 1990). Because of the potential for a long-term carrier state with intermittent shedding of bacteria in milk, segregation should be continued indefinitely for affected cows if possible. Other than clinical testimonials, no reports of successful antimicrobial therapy for mastitis caused by *M. bovis* have been reported. It is thus suggested that therapy should not be a major component of control for this problem.

Practitioners should be aware of the problem just described, especially in herds with a history of recent additions. Clinical episodes of mastitis that consistently do not yield pathogens on culture of milk, or that involve multiple quarters per cow, should be investigated thoroughly. Routine culture of bulk tank milk samples is useful for determining if *Mycoplasma* spp. are present in the herd, although culture of clinical mastitis cases probably offer the best probability to identify infected cows. Consideration should be given to not feed calves with milk from known infected cows to help prevent reintroduction of carriers into the herd once calves mature into first lactation cows.

ENVIRONMENTAL MASTITIS: GOALS, ASSESSMENT, AND CONTROL

In a Pennsylvania study (Erskine et al, 1988), clinical mastitis incidence did not differ in low SCC herds that were essentially free of contagious mastitis, as compared with high SCC herds with a high prevalence of contagious mastitis. As may be expected, the predominant cause of clinical mastitis in the high SCC herds was *Str. agalactiae* and *S. aureus*. The predominant causes of clinical mastitis cases in the low SCC herds were coliforms and streptococcal pathogens other than *agalactiae*. Thus, despite successful implementation of a contagious mastitis control program that is founded on postmilking teat dipping and total dry cow treatment, well-managed herds could continue to have significant mastitis problems. Other reports from Ohio, California, and Michigan have confirmed the importance of clinical mastitis caused by environmental pathogens in well-managed herds that have controlled contagious mastitis, with incidence of clinical cases ranging from 25 to 50 cases/100 cows/year (Hoblet et al, 1991; Gonzalez et al, 1990; Judge et al, 1997).

This section outlines a health management program for herds that have controlled contagious mastitis to a point at which environmental pathogens have become the predominant cause of mastitis. Chronic, subclinical manifestations of IMI caused by environmental pathogens occur, although some pathogens in this group, most notably the coliforms, tend to have transient infections with varied intensity of clinical signs. In addition, because the reservoir of new infection is the environment of the cow and not the parlor or barn where milked, management practices that focus on the prevention of transmission of pathogens during milking would be expected to have little effect on exposure of the teat in the housing of the cow. Thus a management plan for identifying and controlling clinical mastitis caused by environmental pathogens must offer a different perspective from that used to control contagious pathogens.

Goals

Because of the dynamic, rather than static, nature of many environmental IMIs, standard tools that identify prevalence or describe the extent of the problem on any given day are inadequate. Particularly, routine herd culture and monthly SCC reports are poorly correlated both at a herd and an individual cow level with identification and prediction of a clinical mastitis problem. In the Pennsylvania study, whole herd culture yielded low prevalences of IMI for all pathogens, including environmental pathogens. Nonetheless, in the ensuing 6 months many cows were affected with a case of clinical mastitis despite previous negative cultures or low DHI SCC (Erskine et al, 1988). Likewise, it can be more difficult to assess monetary losses from environmental mastitis as compared with contagious mastitis. Chronic IMI caused by pathogens such as *Str. uberis* can be monitored and lost production calculated from LS. However, lost production from transient episodes of clinical mastitis, and treatment costs, especially the cost of discarded milk following treatment, cannot be discerned from DHI SCC records. Thus goals should reflect an understanding of these principles and describe the extent of the environmental problem in a herd in relation to potential economic opportunities (Table 10-4).

Assessment

The NMC Mastitis Control Program emphasizes good record keeping and monitoring of udder health. To assess clinical mastitis incidence and losses, observations and recording of case information must be made daily. This is the most critical opportunity and greatest potential failure for many herd managers in an environmental mastitis control program. Unlike the "automatic" appearance of a DHIA tester at regular intervals to sample the cows, or herd culture of suspect cows that can be done on a convenient basis such as during a herd health visit, recording of clinical mastitis data must be done everyday and on the manager's initiative. With all the other time commitments that demand a dairy producer's attention, this can be a difficult task. It does not matter if information is recorded on computer or written records, as long as it is as complete as possible. Excellent examples of data sheets that can be used for maintaining herd data are presented (Fig. 10-7). Thus the first critical element of assessing clinical mastitis is a record of clinical cases. By simply recording cow, quarter, and date, and subsequently researching the personal data of the affected cow, these records can be vital to determine important risk factors for a herd problem such as days in milk, season, and age. The

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TABLE 10-4

Goals For Monitoring Environmental-Clinical Mastitis

Goal	Level	Frequency of Monitoring
Incidence of clinical mastitis	<2 cases/100 cows milking/month	Monthly
Incidence of severe clinical mastitis*	<2 cases/100 cows milking/year	Monthly
Discarded milk from mastitis therapy	<0.5% of total production/year or <$15/cow in herd/year	Monthly

*Clinical outcome death, agalactia, or culling within 30 days as a direct result of mastitis case.

number of days that milk was discarded for each case should be recorded. This will allow an economic tracking system of the clinical mastitis problem. In herds that utilize daily milk weight technology, economic losses from lost production for each case can be calculated elegantly by comparing milk production after the clinical mastitis case with predicted performance.

The second important focus needed to monitor clinical mastitis in a dairy herd is the bacteriologic culture of milk samples from clinically affected quarters. It is unrealistic to assume that all cases will be sampled. However, if a representative number of cases are sampled (representative not just in number, but in terms of season, age, severity, etc.), bacteriologic data can augment the recorded data in offering a powerful database from which management decisions can be made. Herd personnel will bear the primary responsibility to collect samples, and thus emphasis on aseptic collection technique and collection, before any treatment should be made. Collected samples may be frozen and stored on the farm until collection by the practitioner during a routine visit. Freezing of milk samples for greater than four weeks may decrease the ability to isolate *E. coli* from samples, although not affect isolation of gram-positive cocci (Schukken et al, 1989b). Nonetheless, it is typical to have 25% to 35% of samples not yield isolates; some of this apparent failure is likely due to the short duration of many IMIs that cause clinical mastitis. In addition to epidemiological information, culturing of clinical cases also serves to safeguard a herd from clinical mastitis from unusual pathogens. Between 85% and 95% of bacterial isolates from clinical cases in low SCC herds are coliforms, streptococci, and staphylococci. Consequently, when a high proportion of cultured pathogens other than the three major groups is isolated, an usual mastitis problem should be suspected. Notably, if one type of organism is predominantly isolated, a point source of infection in the environment of the cow, such as contaminated teat dips, water hoses, or intramammary infusions, should be suspected. Accurate records coupled with bacteriology can also positively influence therapeutic decisions regarding clinical mastitis, especially in designing herd level protocol.

Control of Environmental Mastitis

Epidemiology

Coliform is a general term that refers to lactose-fermenting rods of the family Enterobacteriaceae. This group includes the genera *Escherichia, Klebsiella,* and *Enterobacter*. Among herds and cows within herds, a variety of species and serotypes may cause mastitis. Serologically identical strains are rarely found in IMI of different cows within a herd. This suggests a noncontagious nature of coliform mastitis, and the failure of herd management practices that successfully control contagious pathogens to control the incidence of coliform mastitis is well documented. Field studies in herds with low SCCs from Pennsylvania, Ohio, and California have reported average herd incidence of clinical mastitis to be 40 to 50 cases/100 cows annually (Erskine et al, 1988; Hogan et al, 1989b; Gonzalez et al, 1990). Coliform organisms were the single most common group of pathogens isolated from culture in these studies, accounting for 30% to 40% of the clinical cases, and as much as 61% of the cases in which a causative agent was isolated. Although only 10% to 30% of clinical coliform cases are severe (systemic signs), coliform organisms are often the single most important cause of severe clinical mastitis, accounting for 35% of the cases in an Illinois study, and nearly 60% in an Ohio study , but only 15% in a more recent Michigan study (Hogan et al, 1989b; Bezek, 1998). As many as 10% to 15% of cows with severe cases die or have to be culled.

The other major groups of pathogens that frequently cause clinical mastitis are the streptococci, excluding *Str. agalactiae,* and staphylococci. *Str. uberis* and *Str. dysgalactiae* are the two most common streptococcal isolates, although numerous other streptococci and closely related enterococci have been identified as causative agents. Streptococci may account for 20% to 25% of the clinical cases (Bezek, 1998; Erskine et al, 1988; Judge et al, 1997). Incidence of clinical mastitis caused by staphylococci can be more variable but usually accounts for less than 20% of the cases in herds that have controlled contagious mastitis (Erskine et al, 1988; Judge et al, 1997). As with the coliforms, control measures that are successful for contagious pathogens are less successful with the streptococci. However, modest decrease in the prevalence of streptococcal IMI with postmilking teat dipping and dry cow therapy has been reported (Eberhart and Buckalew, 1972), suggesting at least in part a contagious reservoir of infection. Particularly, the dry period is believed to be a critical part of the cow's lactation cycle for new IMI caused by streptococci, and as much as 50% of clinical mastitis cases that occur in the first 60 days of lactation are manifestations of IMI that started in the dry period (Smith, 1985c).

There is considerable variation in the incidence of clinical mastitis between herds. Among 12 herds with low SCC in Pennsylvania, the incidence of clinical mastitis over 6 months ranged from 5 cases/100 cows/year to 123 cases/100 cows/year (Erskine et al, 1988). Thus some herds are able to control contagious mastitis and have a low incidence of clinical mastitis.

Environmental pathogens are ubiquitous but are particularly numerous in bedding and manure. Sawdust bedding

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A

CLINICAL MASTITIS EVALUATION (EXAMPLE 1)

ANYBODY VETERINARY CLINIC
123 WEST PLAIN ST.
NOWHERE, U.S.A.

FARM NAME:_____ MONTH:_____

COW ID	LACTATION NUMBER			CALVING DATE	DATE OF CLINICAL MASTITIS	DIM	CLINICAL MASTITIS BY STAGE OF LACTATION				PEN	CODE	REMARKS (CULTURE OR RESIDUE TEST)
	1	2	3+				<10 DIM	10-100 DIM	100-200 DIM	200+ DIM		R = repeat case N = new case P = problem in previous lactation	
TOTALS:							TOTALS:						

% CLINICAL MASTITIS BY LACTATION NUMBER			
LACT NO.	NO. MILK COWS	NO. CLINICAL CASES	% OF COWS AT RISK
1ST			
2ND			
3+			
ALL			

TOTALS AND PERCENT OF CLINICAL MASTITIS BY STAGE OF LACTATION									
		<10 DIM		10-100 DIM		100-200 DIM		200+ DIM	
LACT NO.	NO. MILK COWS	TOTAL	%	TOTAL	%	TOTAL	%	TOTAL	%
1ST									
2ND									
3+									
ALL									

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NOWHERE, U.S.A.

CLINICAL MASTITIS EVALUATION (EXAMPLE 2)

FARM NAME:_____ MONTH:_____

COW ID	DATE OF CLINICAL MASTITIS	QUARTER(S)	TREATMENT/ DRUG(S) USED	DOSE, ROUTE, TIME (AM/PM)	DAYS TREATED	DATE & TIME MILK OK TO SELL	DAYS MILK WITHHELD	REMARKS (INITIALS, CULL, DEATH OR RESIDUE TEST)

CLINICAL MASTITIS COST ESTIMATE PER MONTH	
TREATMENT COST	
MILK LOSS	
CULL LOSS	
DEATH LOSS	
OTHER	
TOTAL	

TOTAL DAYS TREATMENT = _____

x _____
AVG TRT COST

TOTAL DAYS WITHHELD = _____

x _____ AVG MILK/COW

_____ LB MILK LOSS

x _____ MILK PRICE

$ _____ MILK LOSS

B

FIG. 10-7 A-B, Two sample manual record systems for recording and using clinical mastitis data. *DIM,* Days in milk. (Courtesy of the American Association of Bovine Practitioners.)

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has been incriminated as a factor in increased incidence of coliform mastitis, and straw bedding as a factor for streptococci (Hogan, 1989a). Coliform counts in sawdust bedding have been determined to be higher than counts in sand, fresh cattle manure, and unused sawdust, and *Klebsiella* organisms readily multiply in sawdust (Bramley, 1985). Any bedding material can harbor potential pathogens, particularly those with higher organic content or fecal contamination. Thus a clean dry environment for dairy cattle is probably the most critical factor in the prevention of coliform mastitis. Other factors such as improved understanding of periparturient nutrition, climatic conditions, and use of core-antigen vaccines may also account for decreased incidence of environmental mastitis. In this author's opinion, realistic goals of one to two cases of clinical mastitis per 100 cows per month are obtainable when cows are clean, dry, and comfortable.

In a Pennsylvania study, cows were four to five times more likely to be affected with clinical coliform mastitis in warm, humid periods of the year than in cooler, drier months (Erskine et al, 1988). This seasonal variation in incidence may, in part, be explained by a higher degree of environmental exposure to coliform organisms during the summer months. Considerably higher numbers of coliforms and streptococcal bacteria are isolated from organic bedding sources in summer than in other seasons of the year (Smith, 1985c). Conversely, bacterial numbers isolated from bedding material during winter were lower than those isolated during all other seasons. These findings were consistent with higher rates of new infections in nonlactating cows during spring and summer (Smith, 1985c).

Recently calved cows are at greater risk for being affected with clinical mastitis, especially those in the first month of lactation. In a New York study the incidence of clinical mastitis was four times higher during the first 21 days after parturition than any other 21-day period of lactation (Erb et al, 1984). In Pennsylvania herds, nearly 50% of clinical mastitis cases occurred in the first month of lactation, and 7% of all cows had an episode of clinical mastitis in this 30-day period (Erskine et al, 1988). The increased risk of coliform mastitis for postpartum cows may be associated with a decreased ability of neutrophils to migrate into the gland during infection (Hill et al, 1979). The mechanism may be associated with the cortisol surge that occurs during calving, which in turn decreases neutrophil L-selectin expression (Preisler, 2000). L-selectin is a membrane protein necessary for neutrophils to marginate and initiate diapedesis into a site of infection. A higher incidence of infection also has been reported among older cows as compared with first lactation cows. In addition, despite the near hysterical claims that the use of bovine somatotropin is detrimental for udder health, use of this production enhancement technology by proper label use does not cause increased incidence of clinical mastitis, rate of culling because of mastitis, or discarded milk following therapy of mastitis with antimicrobials (Judge et al, 1997).

A summary of the epidemiology of environmental mastitis includes some key points. The reservoir of infection is the environment of the cow, which causes a wide variety of organisms as causative agents. Mastitis management practices that are successful in controlling contagious pathogens have little success in controlling environmental mastitis. As a result, many of the herds most severely affected with clinical mastitis caused by environmental pathogens have above average production and below average SCC. The periparturient period, warm humid seasons, and increasing age have all been identified as potential risk factors for increased incidence. Consequently, if herd records indicate a clinical mastitis problem and herd SCC are meeting quality milk goals, the control program will likely need to focus on the environment of calving cows, their first 30 days of lactation, and possibly the dry period if streptococci are a problem.

Reduce Exposure

With respect to environmental mastitis, the goal of every dairy farm should be to expose the teat of a cow to as few bacteria as possible. This concept of prevention is simple; the execution can be very difficult. Trends towards increased size of dairy herds, more confinement housing, greater milk production (with subsequent increases in dry matter intake and manure production!), and genetic selection toward production and away from disease resistance are all modern dairy management realities that work against practitioners in the control of environmental mastitis. The demands on producers to manage labor to maintain a clean, dry environment for cattle housing competes with other needs of the dairy enterprise. Housing should account for all climatic possibilities in a given region, not just good weather conditions. Pastures can also pose problems, especially after periods of extensive rainfall. Dairy producers should provide adequate shade to prevent crowding in warm periods of the year, and if portable shading is used, frequent movement about the pasture is recommended. Dry cow housing and particularly maternity areas should receive attention as well. Particularly, for lactating cows, adequate free stall space should be provided for the number of cows in each housing group.

Sand bedding used in well-designed free stalls should be considered as the standard for housing. In some dairy operations this may not be practical because of manure handling and storage facilities or lack of cost-effective regional supply. Sawdust, if frequently changed, such as on a cow mattress system, may offer an alternative. However, in one study, cows maintained on sawdust bedding had an incidence of clinical coliform mastitis 4.5 times higher than herdmates bedded on sand (Bramley, 1985). An Ohio study suggested that addition of lime at 1 part to 10 parts sawdust will raise the pH of the bedding and reduce coliform counts (Hogan, 1995). However, this must be done daily to attain the desired effect.

Other methods to reduce teat exposure to the barnyard environment may offer marginal success. However, no management practice will be successful if the general environment of the cows is otherwise unhygienic. A minimum amount of water should be used in udder preparation before milking. Although research substantiating this practice as a means to reduce incidence of clinical mastitis is lacking, copious amounts of water used to wash udders will eventually cause wash water on the teat end. This and other less-than-desirable practices such as failure to clip udders can eventually lead to greater numbers of bacteria on the skin of the teat and, if nothing else, contribute to higher bacteria counts in milk. As previously stated, drop hoses in parlors that carry wash water for udder preparation have been incriminated as sources of *Pseudomonas* IMI (Erskine et al, 1987c).

As an alternative to wash water for teat preparation, premilking teat dips have been advocated as part of a preparation routine. Premilking teat dipping was reported to reduce the incidence of new IMI infections by 61% in a four herd Vermont study (Pankey, 1989). However, a Pennsylvania study found no benefit of predipping in reducing new infection rate (Unflat, 1985). Due to a lack of published data correlating premilking teat dipping with incidence of clinical mastitis caused by environmental pathogens, a blanket endorsement of this practice as a means to decrease environmental mastitis for all herds cannot be made. It is most likely to be advantageous for herds with demonstrated ability to maintain adequate clean housing for cows. Because of poten-

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tial residues following premilking teat dipping, care should be exercised to thoroughly clean the teats before milking equipment attachment. Acrylic latex and other materials have been added to teat dips to serve as a barrier to the environment. Results have not been consistent. Farnsworth et al (1980) reported a significant reduction in the rate of new coliform IMI in lactating cows when a barrier dip was used as a postmilking teat dip. However, another study did not attain a reduction in new coliform IMI rate (McArthur et al, 1984). In addition, dipping teats once daily for 14 days before parturition did not reduce new infections at calving. While these products are promising in theory, further development is needed. These products should be used in lactating cows in conjunction with monitoring IMI status of contagious pathogens as routine use of some barrier dips, since a postmilking teat dip may not effectively prevent new IMI caused by contagious organisms (Erskine and Eberhart, 1991b).

Enhanced Resistance

The teat sphincter is the primary barrier to infection. Once this defense is breached, secondary and less effective immune mechanisms are mobilized. Key to the secondary line of defense is the neutrophil. Quarters with elevated SCC are more resistant to experimental *E. coli* infection than quarters with low SCC (Carroll et al, 1973). This may explain, in part, why cows in herds with high SCC have greater incidence of coliform mastitis than cows in high SCC herds.

Increased incidence of diseases such as hypocalcemia, ketosis, and displaced abomasums are associated with increased incidences of clinical mastitis. Thus poorly managed nutrition of dry cows, prepartum cows, and cows in the first 30 days of lactation can adversely affect udder health. Antioxidant supplementation also plays a critical role in mammary immune resistance. Selenium and vitamin E supplementation enhances neutrophil killing of phagocytized bacteria. Cows supplemented during the dry period with vitamin E and administered a single injection of selenium before calving had decreased incidence of clinical mastitis (37% reduction) and shorter duration of infection (62% reduction) than unsupplemented controls (Smith et al, 1984). A decrease in clinical mastitis (57%) and duration of infection (40%) during first lactation was observed in selenium and vitamin E–supplemented heifers as compared with unsupplemented controls (Smith, 1985a). First-lactation Holstein cows supplemented with 0.14 ppm dietary selenium had peak bacterial concentrations in milk during experimental *E. coli* mastitis 100 times lower than selenium deficient cows (Erskine et al, 1989). Consequently, selenium deficient cows exhibited diarrhea, dehydration, quarter agalactia, and residual quarter atrophy more frequently than selenium supplemented cows.

One of the more promising methods of enhancing mammary resistance for coliform (and all gram-negative) IMI is by the use of core antigen vaccination. Historically, attempts to immunize cows against coliform infections met with little success. Much of this failure resulted from the diversity of surface ("O" or capsular) antigens presented on invading pathogens. Among herds and cows within herds, a variety of species and serotypes may cause mastitis. Serologically identical strains are rarely found in intramammary infections of different cows within a herd (Eberhart, 1979). However, development of a bacterin derived from the J5 mutant of *E. coli*, a strain that lacks the capsular antigens but retains the lipopolysaccharide core of the cell wall, has proven effective in reducing the severity of coliform mastitis. The lipopolysaccharide core is highly conserved genetically and is phenotypically expressed throughout most gram-negative bacteria. Thus exposure and presentation of the endotoxin antigens in the bacterin to the immune system should lead to nearly universal recognition, and hopefully a response to any gram-negative bacterial pathogen. California studies demonstrated that cows receiving two vaccine doses during the dry period and one dose after calving had an incidence of clinical coliform mastitis of 2.6%, as compared with 12.8% in unvaccinated controls (Gonzalez et al, 1989). A second field trial determined that vaccinated cows had a threefold decrease in clinical coliform mastitis (Cullor, 1991). Subsequent field studies from Ohio have confirmed the benefits of this technology (Hogan et al, 1992b). Titers among cows for naturally occurring serum antibody specific for the J5 strain of *E. coli* were negatively correlated to risk of clinical coliform mastitis in a California dairy herd (Tyler et al, 1988). Similarly, titers in response to immunization were negatively correlated with severity of clinical outcome after experimental challenge of *E. coli* (Hogan et al, 1992a). Experimental challenge models of *E. coli* mastitis have indicated that vaccination with J5 bacterins (1) decreases clinical severity but does not prevent infection, (2) reduces the concentration of bacteria in milk, and (3) is beneficial for multiparous cows as well as primigravid heifers (Hogan et al, 1992a; Hogan et al, 1999). Commercial availability of this vaccine technology has allowed widespread use in many herd mastitis control programs. Despite the potential benefits, these vaccines cannot overcome poor environmental conditions for housing or be expected to affect clinical mastitis caused by non–gram-negative pathogens. However, development of this vaccine has been the single biggest advance in active transfer of immunity against mastitis for dairy cattle and, depending on the incidence of clinical mastitis caused by gram-negative bacteria in a herd, should be considered for a complete mastitis control program.

Therapy of Clinical Mastitis

Guideline 5 of the NMC guidelines for mastitis control promotes appropriate therapy of clinical mastitis. This is a topic that offers considerable variability in clinical interpretation of efficacy, debate as to preferred therapeutic regimens, and frequent testimonials of apparent success. Between 30% and 35% of bacteriologic cultures of milk samples collected from cows with clinical mastitis do not yield any microorganism. Unlike severe clinical mastitis cases, treatment of mild cases (abnormal milk with or without local inflammation of the affected quarter, no systemic signs) is a more voluntary therapeutic decision. Many mild mastitis cases are coliform IMI that are resolved before treatment is necessary. Numerous mild clinical mastitis cases are temporary setbacks in the balance between pathogens and host defenses during the course of chronic IMI. A high proportion of clinical cases observed in cows during the first 60 days after calving, particularly those caused by gram-positive cocci, are manifestations of infections that started during the dry period. In addition, chronic IMI often displays recurring episodes of clinical mastitis at regular intervals, and a small proportion of cows (lactations) often accounts for a disproportionate number of cases (Morse et al, 1987). This poses the major dilemma for treatment of mild clinical cases: Does antimicrobial therapy enhance cure rate over that attained by no treatment (spontaneous cure)? Therapeutic and spontaneous cure rates for clinical mastitis cases caused by coliforms and staphylococci are similar. However, streptococcal IMI, at least if not chronic, may be advantageous to treat.

Information on the therapy of streptococcal clinical mastitis infections is not extensive. Wilson et al (1986) reported 74% of clinical cases caused by *Str. uberis*, and 84% of cases caused by *Str. dysgalactiae* resolved after a single intramammary infusion of cefoperazone. However, bacteri-

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ologic cure was achieved in only 60% to 65% of the cases, and a comparison of cure rate in treated versus untreated cows was not reported. In a study of three California dairies, bacteriologic cure assessed at 4 and 20 days after treatment with amoxicillin, cephapirin, or oxytocin (no antimicrobial) did not differ for mild clinical mastitis cases caused for all pathogens, although antimicrobial treatment led to better clinical cure rates for cases caused by pathogens other than streptococci and coliforms (Guterbock et al, 1993). Thus a "no antibiotic" approach to mild clinical mastitis cases promotes a convenient regimen to avoid costs of discarded milk and residue risks that are inherent in antimicrobial therapy. However, an economic analysis of the California data determined that, although milk production and survival in the herd did not differ between antimicrobial- and nonantimicrobial-treated cows, the rate of both relapses and recurring cases was higher in nonantimicrobial treated cows, especially among streptococcal cases (Van Eenennaam, 1995). A case report from a Colorado dairy also reported an acute increase in incidence of clinical mastitis, prevalence of IMI, and subsequent increase in herd SCC associated with streptococcal IMI following adoption of a no antibiotic approach to clinical mastitis (Cattell, 1996). Administration of supportive care, intravenous oxytetracycline and intramammary cephapirin to cows with varying degrees of clinical mastitis severity caused a higher frequency of normal udder appearance at 10 days (clinical cure), and bacteriologic cure 14 days for streptococcal IMI, and clinical cure for coliform IMI compared with cows administered supportive care only (Morin et al, 1998).

Nonetheless, many herds report success with minimal antimicrobial therapy of clinical mastitis cases. The decision to pursue this option on any dairy must be made on an individual basis, and records of clinical mastitis incidence, SCC, and bacteriologic identification of causative agents should be monitored carefully. However, no matter what the overall herd approach is to new clinical cases in cows, it is rarely efficacious or profitable to administer therapy to milder clinical cases that are chronic and recur repeatedly.

The therapeutic management of severe coliform mastitis is an important concern for veterinary practitioners. Reviews of the therapy of severe coliform mastitis have suggested various treatments, including antimicrobials, supportive fluids, stripping of infected quarters, antiinflammatory agents, glucose, bicarbonate, and calcium (Anderson, 1989; Eberhart, 1979). However, efficacy has not been proven for most of the drugs recommended as therapy for coliform mastitis. In addition, the antimicrobials selected for treatment are usually based on in vitro sensitivity patterns, and because of a high degree of resistance to labeled mastitis therapeutic regimens, typically therapy resorts to extra-label use (Anderson, 1989; McDonald et al, 1977b). These facts, as well as new information regarding the pathophysiology of coliform mastitis, indicate that the traditional approach to therapy should be reconsidered.

After infection, bacterial concentrations in milk increase rapidly. Peak bacterial concentrations in milk often occur within 5 to 16 hours. Subsequently, there is a massive migration of neutrophils into the gland, followed by a rapid decline in bacterial numbers. The inflammatory and systemic changes observed during the course of acute coliform mastitis result from the release of lipopolysaccharide endotoxin as bacteria are destroyed. Endotoxins cause the subsequent activation of numerous endogenous inflammatory mediators, including arachidonic acid metabolites, macrophage-derived monokines, and phagocyte-derived oxygen free radicals (Erskine, 1991a). The severity of acute coliform mastitis appears to be related to the magnitude of the bacterial growth phase and the subsequent cascade of inflammatory events. In order to reduce the severity of these cases, either bacterial growth must be inhibited to prevent high peak concentrations or the effects of endotoxin release must be neutralized.

From a practical standpoint, therapy of acute coliform infections cannot begin until clinical signs appear. Clinical recognition of coliform cases usually occurs well after peak bacterial numbers in the gland have come and gone (Erskine, 1991b). Thus, by the time antibiotic therapy is initiated, the coliform bacteria are in decline and the maximum release of endotoxin has already occurred, which raises questions as to the benefits of antibiotic therapy. Thus early recognition of acute coliform mastitis is extremely important. Limiting the peak of bacterial growth is highly correlated with a successful clinical outcome. Careful examination of the udders and milk at the time of milking, as well as new methods of automatic in-line detection of inflammatory changes, may represent the most meaningful herd-level approach to minimize the effects of clinical coliform mastitis. Therapeutic intervention in coliform mastitis cases should be targeted at reducing the effects of inflammation rather than antimicrobial action. In other words, administration of fluids and effective antiinflammatory agents are more important than antibiotic therapy.

Although antimicrobial therapy may be of secondary importance relative to supportive treatment of endotoxic shock, it remains a practical part of a therapeutic regimen for severe mastitis. Much of our understanding of the pathogenesis of coliform IMI arises from experimental challenge models. However, these cannot be considered as universally applicable for all cases. Occasionally, coliform infections do cause chronic mastitis. Septicemia can occur and has been reported in 15% to 45% of severe cases of coliform mastitis and systemic antimicrobial therapy would be indicated (Powers et al, 1986; Wenz et al, 1998). In addition, numerous other pathogens cause acute clinical mastitis, which can be difficult to distinguish from cases caused by coliforms at initial presentation. Chronic IMI caused by pathogens such as *S. aureus* can become acute or even gangrenous at times of neutropenic dysfunction such as parturition. Severe overwhelming IMI that lead to sepsis can occur during IMI caused by pathogens such as *P. aeruginosa* and *Bacillus cereus*, although antimicrobial therapy for these pathogens may offer little amelioration of clinical outcome. The need for antimicrobial therapy in cows with grossly abnormal milk but with improved appetite, attitude, and milk production, should be evaluated critically. Unnecessary extension of therapy in these instances causes increased discarded milk expense for the dairy producer and risk of antimicrobials in marketed milk. The rational use of approved antibiotics is still indicated, pending confirmation that the infection was actually caused by coliform organisms and that they have been reduced in numbers.

Thus a treatment protocol for clinical mastitis should be established for herds on an individual basis. Records of clinical cases including recurrences, clinical outcome of each case including days of discarded milk and culling, bacterial culture of milk collected from affected quarters, and sound use of pharmacokinetic principles, particularly for drugs selected for parenteral administration, are all needed to ensure the most cost-effective plan.

SUMMARY

Control of mastitis on a farm cannot overshadow the need to balance other aspects of the dairy enterprise, and thus mastitis control programs cannot be initiated without an understanding of the nutritional, reproductive, replacement, and other infectious disease programs that also dictate the

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use of labor and physical facilities on a dairy farm. Nonetheless, information that allows effective mastitis decision making is available in the form of bacterial cultures, SCC, and records of clinical mastitis. Practitioners should use this to some extent on every dairy, although goals may vary. Familiarity of DHIA reports used in the region, potential quality incentives offered by local milk cooperatives, and penalty programs for less than optimum quality milk should be a prerequisite for a mastitis control program. It is also imperative to fully understand and establish a client's drug use protocol and residue avoidance plan.

It is highly recommended that any practitioner who wants to maintain a current understanding of mastitis control participate in organizations such as the American Association of Bovine Practitioners and the NMC. In particular, the NMC has recently released a reference manual for bacteriologic culture of milk samples, which can be considered as the standard guidebook, and should be in the possession of any practice that participates in mastitis control of dairies and particularly if bacteriologic culture of milk is performed.* Mastitis cannot be eradicated from a dairy farm, but it can be reduced to an acceptable level of economic losses to instill pride in a farm's ability to market a quality product.

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APPENDIX A

WORKSHEET TO ESTIMATE MILK LOSS FROM LINEAR SCC

Linear somatic cell count (LS)	Milk Loss (lb/day)*	No. of Cows	Milk Loss
3	1.5	U	1.5 × U
4	3.0	V	3.0 × V
5 (284,000-565,000)	4.5	W	4.5 × W
6	6.0	X	6.0 × X
7	7.5	Y	7.5 × Y
8	9.0	Z	9.0 × Z
9	10.5	ZZ	10.5 × ZZ
Total Milk Loss/Day/Herd	=	Σ of milk loss column products	

Losses are estimates of second and greater lactation cows. Losses for each LS category are one-half that of older animals. Multiply the number of cows in each category by the milk/loss/day factor. Sum total all the products for the milk loss /day/herd. Multiply this total by the market value of milk to determine the economic loss per day.

Example Herd

Linear SCC (LS)	Milk Loss (lb)/Day*	Number of Cows ≥2 lactation(1st lactation)	Milk Loss (lb/day)
3	1.5	5	7.5
4	3.0 (1.5)	10 (4)	30 (6)
5 (284,000-565,000)	4.5	4	18
6	6.0	6	36
7	7.5 (3.75)	2 (2)	15 (7.5)
8	9.0	4	36
9	10.5	0	0

Total milk loss/day/herd = 142.5 lb/day + 13.5 lb/day for 1st lactation
= 156 lb/day relative to linear score of >3.0

DHI SCC summary (see Fig. 10-2, *B*) calculates loss on average LS for herd on test date. This was 5.3; this LS = 4.5 lb/day assessed on all cows in herd, 41 cows in herd = 184.5 lb/day. summa

*Milk loss = 1.5 lb/day for cows ≥2 lactations; 0.78 lb/day for lactation = 1 (from Raubertas and Shook, 1982).

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APPENDIX B

CULLING COWS TO ATTAIN A SOMATIC CELL COUNT

1. **PARTIAL BUDGET FOR CULL COWS** (75 lb/day/cow; 305-day lactation)

Increased revenue	\$0.35/lb × 1,400 lb − auction fees	\$455
Decreased costs	\$6/day × 305 days	\$1830
Decreased revenue	75 lb/day × \$ 0.13/lb × 305 days	\$2975
Increased costs		\$0
TOTAL (loss from culling cow)		−\$690

This assumes a 75 lb/day average for the herd and projects potential losses-gains for an ensuing 305-day lactation. It is difficult to assess potential gains from removing a cow with contagious mastitis from the herd (removal of a reservoir for new IMI) and potential gains for culling of cow with other potential health problems). Use of potential replacement heifers is not in model.

2. **POTENTIAL GAIN AT HERD SCC LEVEL** (refer to Table 10-2)

= Co-op bonus + FMO Bonus
= [Value of milk (\$/cwt) × cwt milk marketed/year] + [\$/lb protein × (lbs milk/yr × mean % protein of marketed milk)

Other bonuses may apply, such as volume bonus for larger herds if a specific SCC is attained

Example Herds (refer to Table 10-2 for bonus information)

Example 1: Removal of 5 cows results in bulk tank somatic cell count (BTSCC) decrease from 310,000 to 260,000
100 cow dairy; 75 lb DM; 3.2% protein
Cull Cow Loss + Herd Bonus
−\$ 3450 + 0.05/cwt × 27,375 cwt + 0.01/lb protein × 87,600 lb protein
−\$ 3450 + \$ 1370 + \$876
−\$ 1204 loss from culling 5 cows

Example 2: Removal of 5 cows results in BTSCC decrease from 220,000 to 190,000
100 cow dairy; 75 lb DM; 3.2% protein
Cull cow loss + Herd Bonus
−\$ 3450 + 0.10/cwt × 27,375 cwt + 0.02/lb protein × 87,600 lb protein
−\$ 3450 + \$ 2737 + \$ 1752
+\$ 1039 gain from culling 5 cows

Example 3: Example herd (recorded in Fig. 10-2, A); 41 cows milking, 31 lb of milk/day average, 3.2% protein; Cull cow # 31, cow # 45, Carol, and Connie to lower herd SCC to 381,000 (projected from DHI-520) and no longer pay penalty for protein price (Milk Order 40). Culled cows producing a total of 175 lb/day: potential lost revenue for 305 days is 53,375 × \$ 0.13 = \$ 6940 (for all four cows); potential increased revenue and decreased costs are \$2285/cow × 4 cows = \$ 9140; total from culling cows \$2200 gain

Cull cow loss + Herd Bonus
\$ 2200 [SCC bonus = 0] + [0.11/lb protein × 14,845 lb protein]
\$ 2200 + \$ 1633
\$ 3833 gain from culling 4 cows

This model is based on U.S. pricing system in which milk quotas are not involved in the marketing. Gains/losses are projected for 1 year after culling of cows to attain a SCC level. Results will vary depending on price of milk, protein, cull cows, and daily milk production per cow/day. However, the assumption for potential gain relies on the ability for the farm to maintain the lower SCC level, and thus attain the improved price bonus for milk, for 1 year. This implies that IMI will be prevented effectively and any new IMI in the herd will not cause elevated SCC, or additional cows will need to be culled to maintain the SCC bonus.

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CHAPTER 11

Dairy Cattle Nutrition

BRIAN J. GERLOFF

There is probably no aspect of a dairy enterprise that has wider impact than the feeding program. Dairy farm feeding programs have direct effects on production and growth and set the stage for future productive potentials. Many health problems on a dairy relate in some way to the feeding program. Feed costs on the average dairy account for more than 60% of total operating expenses in the United States (USDA, 1988). A significant part of the average dairy's labor force devotes its time to planting, growing, harvesting, mixing, and feeding rations to a variety of animals. Investments in equipment used in feeding programs are an important part of the dairy's debt load. Small changes in feeding programs may bring about large changes in productivity, health, income, feed costs, labor allocation, and debt load. The total savings from small changes can be substantial. Without considering improved production or health effects, one study has shown that routine nutritional consultation by veterinarians can save 14% of total feed costs on dairies (Ferguson et al, 1987).

For all these reasons, veterinarians who intend to serve their dairy clients on a herd basis must become actively involved in the herd's feeding program (Gerloff, 1991). Dairy herds are commonly fed unbalanced, expensive rations (Ferguson et al, 1987). By serving as independent consultants, veterinarians can provide unbiased advice to their clients. Those veterinarians who wish to serve their clients at a herd level constantly find their attention focused on the feeding program. The next recumbent, hypocalcemic cow raises questions about dry cow feeding. The next anestrous, thin cow with smooth ovaries raises questions about early lactation energy levels in the ration and dry matter intake (DMI). The next time the herd average mature equivalent milk production falls by 500 lb, the problem generates the same sense of urgency as a cow with a prolapsed uterus. As a profession, dairy veterinary medicine must come to grips with the fact that it cannot truly serve client needs by practicing therapeutic medicine separately from nutritional consulting. Veterinarians must train themselves to deal with nutrition directly, consistently, and knowledgeably.

In recent years, as herd size has increased, many dairies have come to rely on a team of advisors rather than only one or two. A nutritional consultant, local veterinarian, and outside consultant may all be providing advice to a dairy. In these circumstances, communication about the feeding program and resulting performance is critical. It is imperative that the veterinarian be knowledgeable about dairy nutrition and involved in ration formulation. The veterinarian needs to maintain their involvement as part of the advisory team.

LEVELS OF NUTRITIONAL SERVICE

Having decided to be involved in a dairy's feeding program, the veterinarian and client should first agree on the level of nutrition service that is to be provided. The level varies from herd to herd, depending on the veterinarian's expertise, the client's ability and interest, and the role being played by other consultants to the farm. There are essentially four levels of service that might be provided:

Level 1: Problem Identification and Analysis

At level 1 the veterinarian takes on the task of monitoring the dairy herd for indicators that there might be nutrition-related problems. Many areas need to be monitored: production, milk components, DMI, body scores, disease rates, growth rates, and feed costs. Based on these monitored areas, the veterinarian can call attention to problems as they arise, form and test hypotheses about likely causes, and interact with other farm service personnel as the problems are addressed.

Level 2: Ration Analysis

At level 2 the veterinarian evaluates the nutritional adequacy of diets as they are fed to the cows. If problems of balance or economics are identified, they are referred to the appropriate person for reformulation. This level is difficult to sustain over time because, after a while, the person formulating the ration is likely to resent being "second-guessed." It can work well if the "team approach" is part of the procedure on the dairy.

Level 3: Ration Formulation

At level 3 the veterinarian takes on the responsibility of formulating the ration. To operate responsibly at this level, veterinarians need several additional skills beyond those traditionally taught at veterinary colleges. The veterinarian must know how to use a computer to formulate a balanced, deliverable, cost-effective ration. The veterinarian should have experience in the daily mechanics of how feeds are handled and how cows are fed. It requires an intimate knowledge of the farm and its personnel. The veterinarian must maintain daily contact with the feed industry so that feed prices and availability can be factored into the farm's overall feeding program.

If not managed carefully, this level of service has several pitfalls. It lacks the on-farm follow-up, supervision of implementation, and monitoring of results that are included in level 4. There is a truism about feeding dairy cows that every cow has three rations: the one **formulated,** the one **delivered,** and the one **actually eaten.** The best feeding programs minimize the difference among these three rations. If the veterinarian's role stops at formulation, then mistakes can occur in delivery and feed bunk management that can doom the program to failure. If the program fails, the veterinarian's formulation is likely to be blamed.

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Level 4: Total Program Consulting

Level 4 of nutritional service includes those aspects missing in level 3. The veterinarian plays an active role in implementing the feeding recommendations. Attention is paid to areas such as bunk management, cow comfort, feeding frequency and scheduling, quality control, and consistency of feeding management. Working closely with the producer, plans for future forage production can be generated, including attention to factors such as timing the harvest for maximum feed value. The monitoring described in level 1 is sustained, and timely adjustments and feedback are provided to ensure that the rations are accomplishing the desired ends. In the long term, this is the level of service that is most desirable for both the veterinarian and the client. The producer benefits from the added supervision and support, and the veterinarian can assure the client that the program is carried out as designed. If the program is not working, it can be modified. Total program consulting can be accomplished with the veterinarian as a part of the team that would include the nutritionist, as well as by the veterinarian alone. With many larger herds, particularly, multiple outside consultants are used, and a team approach provides the owner with the best opportunity for expert advice. In many herds the veterinarian is best suited to be the "team leader."

DIGESTIVE PHYSIOLOGY OF THE DAIRY COW

The fate of feeds eaten by the dairy cow is more complex than in monogastric species. The cow's rumen contains a complex ecosystem of microbes that is necessary if the cow is to break down fiber that would otherwise be indigestible (Hoover and Miller, 1991). The rumen florae are also able to use nonprotein nitrogen sources for microbial protein synthesis. This microbial protein is then available for digestion by the cow. Rumen motility, regurgitation, cud chewing, and salivation serve to mix the contents, reduce particle sizes, and provide a stable environment for optimum microbial activity. Any consideration of dairy cattle nutrition must begin with the rumen. Maintaining the efficient performance of this complex fermentation vat is necessary to optimize both production and health of the dairy cow.

The rumen is a complex ecosystem. Fermentation of dietary components in the rumen causes the growth of microbes (primarily bacteria) and the production of volatile fatty acids (VFAs). VFAs are responsible for approximately 70% of the energetic needs of a high producing dairy cow, and microbial mass is responsible for supplying approximately 65% to 70% of the protein requirements. Bacterial species comprise the largest number of organisms and the greatest mass. Bacterial concentrations can be 10^{10} cells/g of rumen contents and have been classified according to shape, size, or substrate fermented. Box 11-1 shows one classification of rumen bacteria. The balance between these species populations will be affected primarily by the substrate available for fermentation. Protozoa are typically present in large numbers and are present at a greater relative percentage on high forage diets, approximately 10^5 to 10^6 cells/g. Protozoa actively ingest bacteria, and their net effect on fermentation efficiency is debatable. Their presence, however, is generally regarded as suggestive of a healthy rumen ecosystem. Fungi are also present, as are phages or virus-like organisms whose involvement in rumen dynamics is little understood (Penn State Extension Service, 1999). A macroscopic view of the rumen would show a compartment with four strata. The topmost would be a gas layer, filled with the gases produced from fermentation, including carbon dioxide and methane. The next layer would be a floating fiber mat, comprised of longer pieces of buoyant plant material floating on the liquid layer, which could be considered to be the third stratum. The liquid layer also contains small, saturated food particles suspended within it. The fourth layer would include dense particles on the floor of the rumen and reticulum. This may include food particles as well as stones, sand, and gravel.

The rumen microbes are sometimes described according to their location in the various rumen environments. These include the liquid phase, where bacteria and protozoa exist and metabolize soluble carbohydrate and protein. These microbes in the liquid phase are removed from the rumen relatively quickly—as liquid leaves. They are relatively fast growing. A small number of bacteria are attached directly to the rumen epithelium. In the third, or solid phase, microbes attach directly to the food particles. This is where digestion and metabolism of most of the less readily available carbohydrate and protein fractions of feedstuff particles occurs. Attachment, digestion, and fermentation must happen before the fibrous feed particles leave the rumen, or they will remain undigested. Slower growing bacteria (as are most cellulolytic and other fiber-digesting bacteria) require an adequate length of time attached to particles in the solid phase to prevent their depletion and removal from the rumen. It should be apparent that there is a complex interaction between rumen microbial species, substrate, rumen retention time, and passage rate that will affect the efficiency of digestion, VFA production, rumen microbial production, and, subsequently, whole animal performance and health. A large influence on this ecosystem is the floating fiber mat. The mat retains smaller particles, keeping them in the rumen longer, and allows more complete fermentation.

Carbohydrates account for a majority of the dry matter in a cow's diet. Most of these sugars, starches, pectins, and fiber (cellulose and hemicellulose) in the cow's ration are broken down in the cow's rumen. When the rumen microbes break down these carbohydrates, they produce the VFAs acetate, propionate, and butyrate. The rumen wall can absorb these metabolites (Linn et al, 1989). Feeds leave the rumen based on density (specific gravity) and particle size (Welch, 1986). The density of the mat of floating long fiber also affects the passage of feedstuffs from the rumen (Van Soest, 1982). Fiber with small particle size may escape the rumen before there is enough time for the cellulolytic microbes to digest it (Ruckebusch et al, 1991). Smaller particles are rapidly saturated and fall to the bottom of the rumen. From there they move forward to the reticulum and out through the reticuloomasal orifice (Swenson, 1984).

Longer fiber length also serves to encourage eructation, cud chewing, and salivation. The rumen is most efficient as a fermentation vat if conditions within it are held stable. The bicarbonate and phosphate ions secreted in the saliva during cud chewing are a major source of buffering capacity for the rumen, and the saliva provides 70% of the water present in the rumen (Bartley, 1976). A cow may produce 100 to 200 L of saliva per day. Total saliva production is fairly constant for total mixed rations (TMRs) that use differing silages (corn silage versus haylage) (Cassida and Stokes, 1986), but can vary widely if more disparate feedstuffs are fed (Bailey, 1961).

Depending on the nature of the ration, cows chew their cud between 20% and 40% of the day (Beauchemin, 1991; Shaver et al, 1988). Total chewing time (both eating and cud chewing) should be between 10 and 11 hours per day or longer (Beauchemin, 1991; Sniffen, 1988). Cows tend to chew their cud while resting. In a comfortable environment most cows should be lying down while chewing their cud. Between 60% and 70% of resting cows should be chewing their cud. Cud chewing serves to reduce fiber particle size, making those particles more accessible to the cellulolytic microbes in the rumen.

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BOX 11-1

*Rumen Bacteria Grouped According to Substrate Preference**

CELLULOLYTIC SPECIES
Bacteroides succinogenes
Ruminococcus flavefaciens
Ruminococcus albus
Butyrivibrio fibrosolvens

PECTINOLYTIC SPECIES
Butyrivibrio fibrosolvens
Bacteroides ruminicola
Lachnospira multiparis
Succinivibrio dextrinosolvens
Treponema bryantii
Streptococcus bovis

UREOLYTIC SPECIES
Succinivibrio dextrinosolvens
Selenomonas sp.
Bacteroides ruminicola
Ruminococcus bromii
Butyrivibrio sp.
Treponema sp.

SUGAR UTILIZING SPECIES
Treponema bryantii
Lactobacillus vitulinus
Lactobacillus ruminus

ACID UTILIZING SPECIES
Megasphaera elsdenii
Selenomonas ruminantium

PROTEOLYTIC SPECIES
Bacteroides amylophilus
Bacteroides ruminicola
Butyrivibrio fibrosolvens
Streptococcus bovis

LIPID UTILIZING SPECIES
Anaerovibrio lipolytica
Butyrivibrio fibrosolvens
Treponema bryantii
Eubacterium sp.
Fusocillus sp.
Micrococcus sp.

HEMICELLULOLYTIC SPECIES
Butyrivibrio fibrosolvens
Bacteroides ruminicola
Ruminococcus sp.

AMYLOLYTIC SPECIES
Bacteroides amylophilus
Succinimonas amylolytica
Bacteroides ruminicola

*Adapted from Penn State Extension Circular 422, From feed to milk: understanding rumen function, Table 5.

Rumen pH has a profound influence on rumen efficiency, VFA production, and overall animal health. The pH (concentration of free hydrogen) is influenced by many factors, including rate of acid production, rate of acid absorption and removal, which specific acids are produced (lactate versus butyrate versus acetate versus propionate), saliva and bicarbonate secretion, and buffering capacity of the feed. The physical form and constituents of the diet, as well as the total amount and proportion of concentrate, also influence the pH (Allen, 1995). Cellulolytic bacteria and methanogenic bacteria are favored at a pH of 6.0 to 6.8. As the pH drops, starch and sugar digesters are favored, with their preferred range being 5.2 to 6.0. As pH drops from 7.0 to 5.2, the proportion of acetate produced declines and propionate increases. As pH drops further, lactate production increases and all others decline. The "optimum" rumen pH is dependent on diet. It involves production of a maximal amount of VFAs without significantly inhibiting cellulose digestion. Rumen pH below 5.5 to 5.6 has been associated with health problems such as laminitis, ketosis, and LDA (Nordlund, 1995). These diseases have commonly been grouped together and referred to as subclinical acidosis. In most dairy cattle diets, then, the optimum pH should probably be between 5.8 and 6.3. This range balances the desire for rapid microbial growth and VFA production with the need to maintain an active cellulolytic population and avoid negative health effects on the whole animal.

Rumen microbial growth, then, is affected by such factors as the composition of the feed (substrate); particle size (affecting where and in which layer the particles end up); feeding pattern; salivation (fluid and mineral flow); intake (affecting passage rate and how long the particles stay in the rumen); rate of carbohydrate fermentation; and availability of adequate nitrogenous substrate (ammonia, peptides, and amino acids) for microbial growth. Attempts by computer models to predict bacterial growth rates should theoretically account for all of these effects. Rudimentary efforts, including those of the National Research Council (NRC) (1989, 2001), predicted rumen microbial protein production based only on energy and crude protein content of the diet. Successive computer programs refined this to make predictions based on energy—discounted for the fat content—and degradable or available protein (Spartan Ration Evaluator, 1992). More recent attempts at mechanistic model development have further increased the sophistication of these predictions (Russell et al, 1992; Sniffen et al, 1992; Fox et al, 1992; O'Connor et al, 1993).

A truly accurate model of the rumen would predict the fermentation rates of each component of each feed. It would predict the end products of fermentation (or which specific VFAs) are produced; the microbial mass produced by the fermentation; the rate of passage of both unfermented feed and the microbial mass out of the rumen; the chemical composition of these substances; and their digestive fate in the lower gastrointestinal tract. To accomplish this would require not only knowledge of the bacteriological processes in the rumen but also a means of predicting the physical movement of each feedstuff particle in the rumen milieu. Both the knowledge and mathematical computing power are inadequate to develop this complex a model. Yet many

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observations and measurements have been made, which allow more and more precision in predictions of rate of feedstuff fermentation and bacterial production. These observations include both in vitro and in vivo systems. Drawing on this literature has caused preliminary attempts to more accurately model rumen dynamics and formulate rations using those models.

Models currently in use attempt to characterize the rate of carbohydrate digestion of a feed—including neutral detergent fiber (NDF), starch, sugars, other nonfiber carbohydrates, and lignin—and predict the feed's rate of passage from the rumen, based primarily on the level of DMI. These factors are combined to mathematically estimate the amount of carbohydrate available for microbial fermentation and to predict energy availability and bacterial yield. Similar calculations are developed to predict protein, peptide, and ammonia availability in the rumen based on estimates of the rate of digestion of the protein component of the feed and its passage rate through the rumen. These concepts then allow an estimate of the bacterial production and feed (especially protein) bypassing the rumen with more accuracy and precision. The models provide opportunities for significant improvement in practical and conceptual applications in dairy nutrition (CPM Dairy, 1998; NRC, 2001).

Once past the rumen, the digestive process in the cow proceeds similarly to that of monogastrics, except that the cow digests both the ingested nutrients that have bypassed ruminal degradation and the microbial population that has been washed out of the rumen.

FACTORS AFFECTING NUTRIENT REQUIREMENTS

The high-producing dairy cow does a prodigious amount of metabolic work. She may consume 25 kg or more of dry matter, expend 40 Mcal of net energy, and use 4 kg or more of protein per day. Nutrient needs vary, depending on breed, body size, stage of lactation, milk production, fat content of the milk, gestation, environment, and feed digestibility. The nutrient requirements of lactating cows have been published by the National Research Council (NRC, 2001). The 2001 guidelines represent a comprehensive summary and review of the literature over the last 12 years, and can be considered a necessary reference for professionals involved in offering advice and consultation on the topic of dairy nutrition. Specific changes include: a more detailed rumen model of carbohydrate and protein utilization; an attempt to quantitate specific bypass amino acid requirements for milk production; and expected changes in dry cow nutrition requirements.

Lactation Cycle

There are five phases in the cycle of lactation from one calving to the next. The first phase is from calving through peak milk production, about the first 10 to 12 weeks of lactation. During this phase, the cow's level of milk production increases rapidly to peak near the end of the phase (Fig. 11-1). The butterfat content of the milk starts high and decreases. Both of these are natural adaptations to the needs of a nursing calf, augmented by generations of genetic selection. Feed intake (DMI) increases too but lags behind the demands of the rapidly increasing milk production. The cow calls on body fat reserves to fill the difference between energy intake and energy needs. The cow loses weight during phase 1. Protein in the ration must be high during this phase because the cow's ability to mobilize body protein for milk synthesis is limited. If protein intake is too constrained, the cow does not reach her genetic potential for milk production.

Phase 1 is the most difficult phase for feeding. The cow must adjust from eating a high-fiber, low-energy-density, dry cow ration to a high-energy, constrained-fiber, lactating cow ration. She must compensate for dramatic increases in mineral turnover. Cows are in negative energy balance and have limited DMI capacity. Phase 1 is the phase during which almost all metabolic diseases occur. Phase 1 cows often have infections of the uterus and/or mammary gland. These infections are another metabolic demand and may further reduce appetite and DMI.

In phase 2 (weeks 12 to 24 of lactation), the cow's DMI gradually rises until her nutrient intake matches her level of production. The cow should no longer be losing weight; in fact, she may begin to regain some of the weight lost in phase 1. The feeding challenge in phase 2 is to sustain peak production as high as possible while supporting the cow as she is bred and begins the next gestation. If BST is used, it is usually started during phase 2. This may increase the nutrient requirements of this cow but should not alter the basic relationships.

Phase 3 (approximately weeks 24 to dry off) completes the lactation and is the longest phase of the cycle. Milk production gradually declines and butterfat content rises slightly during phase 3. DMI also falls off in response to the cow's decreasing nutrient needs with declining production. During this phase the cow can consume enough dry matter to more than support her production. The weight lost in phase 1 should be restored and gestation of the next calf supported. If cows are fed only to support their current milk production in phase 3, then the reserves of fat are not restored and peak production in the next lactation suffers.

Phase 4 is the early dry period, The entire dry period should last for 6 to 8 weeks before the next calving. Phase 4 includes all except the last 3 weeks. Dry cows should be fed a separate ration tailored to their needs. Rations should be based dominantly on forages and should be supplemented adequately with vitamins and minerals to support the advancing pregnancy and approaching lactation. The mineral balance should be monitored to avoid metabolic diseases at calving. Although the dry cow should gain some weight because of the growing conceptus and fluids, under ideal conditions the cow's body condition should not change during the dry period.

Phase 5 is the late dry period, sometimes called the transition period, that occurs in the last 3 weeks before calving. The feeding program during this period is critical as a period for adaptation to the lactating cow diet and for meeting the nutrient needs of a cow in dramatic metabolic transition as she prepares for calving and milk production (but within the constraints of a significant drop in DMI). Most metabolic disease problems are triggered by an inadequate phase 5 diet, and a more detailed discussion of this phase occurs in the section on feeding the dry cow and metabolic disease.

First-lactation heifers present an additional challenge during all phases of the cycle. They must not only respond to the challenges of lactation but must also continue to grow to maturity. DMIs are lower in heifers than cows producing the same amount of milk. This is partly the result of body size, but on many farms it is also a function of competition and feeding strategies.

Environment

The cow's environment can have a profound effect on feed intake and nutrient metabolism (NRC, 1981). The thermoneutral zone for cows is from approximately 0° to 16° C

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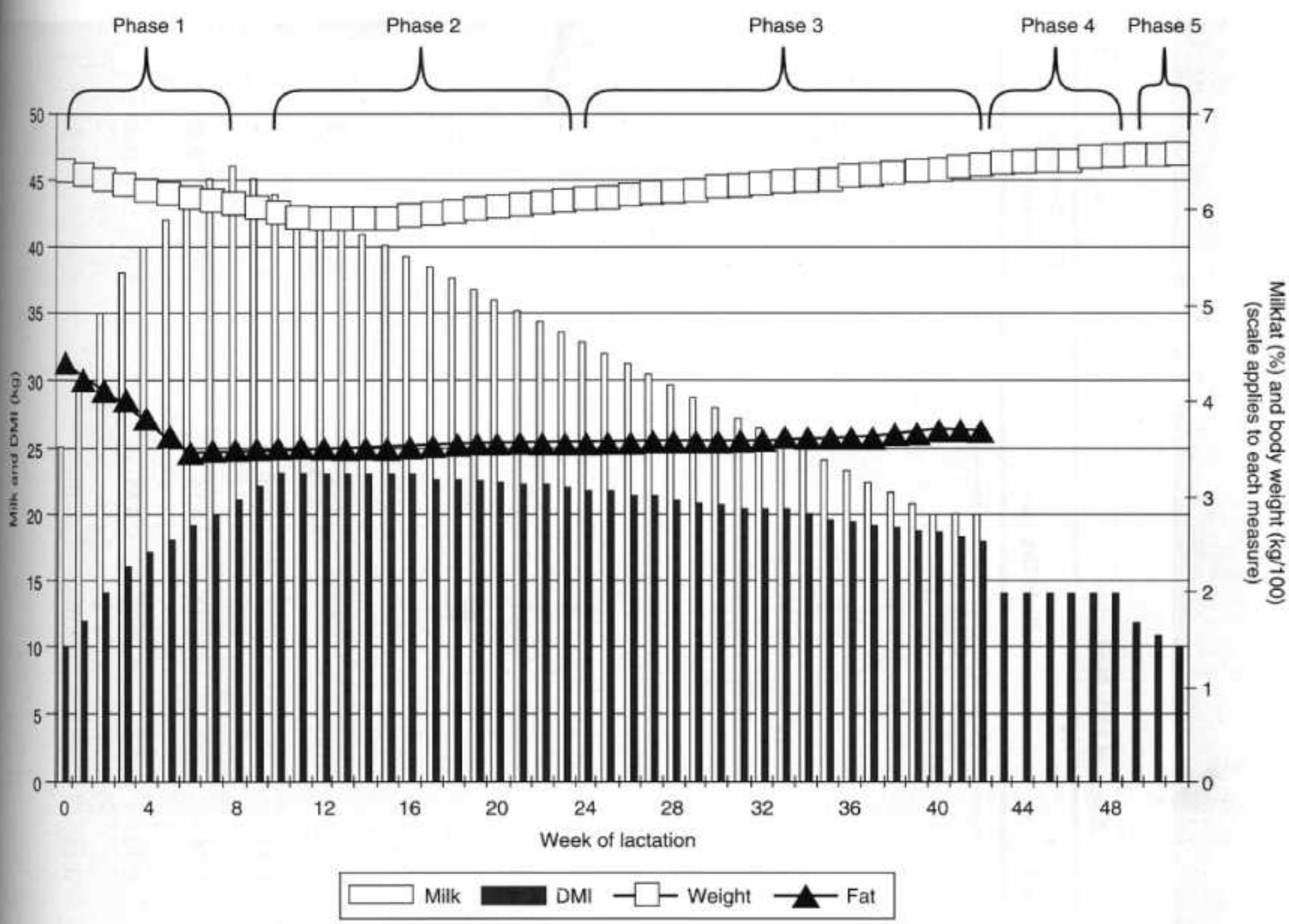

FIG. 11-1 Dairy cow lactation cycle. *DMI*, Dry matter intake.

(32° to 61° F), although some acclimation can occur (NRC, 1981). Cows in cold environments (lower than −20° C, or −4° F) may consume as much a 35% more dry matter than cows at a more thermoneutral temperature (10° to 20° C, or 50° to 68° F) in order to compensate for their increased energy requirements. Intakes begin to decline with heat stress above 25° C (77° F) and show a significant decline above 30° C (86° F). At 40° C (104° F) intake may be only half the intake at 20° C (68° F). To compound these problems, maintenance energy requirements actually increase in cows exposed to more than a few hours per day of temperatures greater than 30° C (86° F). The effects of heat are less if the cow has access to shade or moving air or is in a climate with lower humidity. Access to water is also important. Water intake may double as the temperature rises from 15° to 30° C (59° to 86° F). The amount of exercise also affects the cow's requirements. Most published requirements assume minimal exercise. Pasture systems may increase the energy requirement by 20% or more (NRC, 2001).

Cow Comfort and Competition

In addition to ambient temperature, humidity, and wind, the physical and social environment of the cow have an effect on feed intake. Heifers are particularly susceptible to reduced intake because of competition, proximity of "boss cows," and limited access to feed bunks. In open access feed bunks, there should be a minimum of 60 cm of bunk space per animal, and for optimum intake 75 cm may be better (Sniffen, 1991). If feed is available at all times, cows eat as many as 12 "meals" per day. Restricted access to feed reduces this number and decreases total intake. Cows spend a large amount of time per day ruminating, and conditions should encourage them to lie down while chewing their cud. Cows perform better if housed and managed in a clean, quiet environment and handled in a gentle, consistent manner.

NUTRIENT REQUIREMENTS OF DAIRY COWS

Table 11-1 provides the general nutrient requirements of mature dairy cows at moderately high and middle ranges of milk production and as dry cows (NRC, 1989, 2001; Penn State Extension Service, 1995). The NRC supplies a microcomputer program on disk that can calculate nutrient requirements for various classes of cattle and provides a concise summary of recommended levels of nutrients for each class of animal, including required and maximum tolerable levels of nutrients. It is important to remember that the NRC values are not absolutes. Experienced nutrition consultants almost always modify NRC requirements in keeping with their own particular experience and to match the particular

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TABLE 11-1

*Nutrient Requirements for Dairy Cattle**

Parameter	Stage of Milk Production							
	Moderately High		Midrange		Early Dry Cow		Late Dry Cow (Transition)†	
Milk production (kg)	36		18		0		0	
Butterfat (%)	3.8		3.8					
Weight (kg)	650		650		650		650	
Dry matter intake (DMI) (kg)	22		16		11		10	
Net energy of lactation (Mcal and Mcal/kg)	36	1.65	23	1.50	13	1.25	15	1.54
Crude protein (kg and % DMI)	3.7	17	2.2	14	1.3	12	1.4	14
Undegraded protein (kg and % DMI)	1.3	6	0.8	5	0.3	3	0.4	4
Percentage undegraded (% crude protein)	35		35		29		30	
Acid detergent fiber (kg and % DMI)	4.2	19	3.4	21	2.8	27	2.4	24
Neutral detergent fiber (NDF (kg and % DMI)	5.5	25	4.5	28	3.7	35	3.3	33
NDF from forages (kg and % DMI)	4.8	22	3.5	22	3.1	28	2.6	26
Calcium (kg and % DMI)	0.14	0.65	0.08	0.53	0.04	0.39	0.05	0.5
Phosphorus (kg and % DMI)	0.09	0.42	0.05	0.34	0.03	0.24	0.03	0.32
Magnesium (kg and % DMI)	0.05	0.25	0.03	0.20	0.02	0.16	0.02	0.22
Potassium (kg and % DMI)	0.22	1.00	0.14	0.90	0.07	0.65	0.08	0.80
Sodium (kg and % DMI)	0.04	0.18	0.03	0.18	0.01	0.10	0.01	0.10

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Chloride (kg and % DMI)	0.05	0.25	0.04	0.25	0.02	0.20	0.02	0.20
Sulfur (kg and % DMI)	0.04	0.20	0.03	0.20	0.02	0.16	0.02	0.17
Iron (mg and ppm DMI)	2200	100	1600	100	1100	100	1000	100
Cobalt (mg and ppm DMI)	4	0.2	3	0.2	2	0.2	2	0.2
Copper (mg and ppm DMI)	330	15	240	15	165	15	150	15
Manganese (mg and ppm DMI)	968	44	704	44	480	44	440	44
Zinc (mg and ppm DMI)	1540	70	1120	70	770	70	700	70
Iodine (mg and ppm DMI)	11	0.5	8	0.5	5	0.5	5	0.5
Selenium (mg and ppm DMI)	7	0.3	5	0.3	3	0.3	3	0.3
Vitamin A (IU and IU/kg DMI)	169,008	7700	123,000	7700	85,000	7700	77,000	7700
Vitamin D (IU and IU/kg DMI)	36,000	1650	26,000	1650	18,000	1650	16,500	1650
Vitamin E (IU and IU/kg DMI)	968	44	700	44	800	77	770	77

DMI, Dry matter intake.
**Mature cow, third lactation; assumes no weight changes.
†If anionic salts are added to the diet, adjustments in macromineral concentrations are needed.
Adapted from the National Research Council: *Nutrient requirements of dairy cattle*, ed 6, Washington, DC, 1989, National Academy Press (revision), Table 6-5; Penn State Dairy Reference Manual, ed 3, NRAES, 1995, Tables 5.35 and 5.36.

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herd's needs, feed ingredients, and production levels. The NRC values should be used as guidelines, not absolutes. The text of the NRC and other nutrition references should be consulted for detailed information. The revised NRC guidelines (NRC, 2001) have suggested some adjustments in calculating energy, protein, and mineral concentrations of diets. Many of these adjustments are based on a more dynamic model of rumen function, dependent on DMI. The NRC provides a CD-ROM with the reference text that incorporates these changes.

The NRC uses a "factorial" method for calculating requirements. Whether the nutrient in question is energy, protein, or a mineral, the total requirement is arrived at by estimating requirements for maintenance, growth, reproduction, and production, and then summing these individual factors. The amount supplied is estimated by discounting the gross amount in the diet by factors for digestion and absorption, metabolism, and tissue utilization efficiency. It should be appreciated that calculations of both requirements and amounts supplied are dynamic values, changing under various circumstances. This is especially true when estimating amounts supplied, because of the complexity of interactions within the rumen.

It is important to remember that the recommended proportions of nutrients such as those in Table 11-2 are based on the assumption that the animal being fed is eating "normal" amounts of total ration—that is, its DMI is normal. This is a critical point. When considering feeding programs, nutritional consultants commonly communicate in a complex subdialect of numbers. Usually, these numbers are some proportion of the ration. For example, they might refer to 1.65 Mcal/kg, or 17% protein, or 40 ppm of manganese. Each of these numbers is a proportion, usually of DMI. Ratios are also commonly used—for example, a 60:40 ratio of forages to concentrates or 3:1 ratio of vitamin A to vitamin D. Proportions and ratios are useful shorthand for communication, but keep in mind that the cow's requirements are not satisfied by balanced ratios. The cow requires absolute amounts of each nutrient. She requires total megacalories of energy, kilograms of protein, and milligrams of manganese. Proper proportions in a diet satisfy the cow's requirements only if her total dry matter intake is adequate. If she eats too little of a "balanced" ration, her requirements remain unfilled.

Dry Matter Intake

When veterinarians formulate rations for high-producing dairy cows, DMI should be the first consideration. In maximizing milk production, DMI is the single most constraining factor in feeding lactating cows. Numerous factors influence DMI: body weight, forage quality and digestibility, stage of lactation, milk production levels, butterfat content of the milk, exercise, environment, management, cow comfort, social interactions, body condition, ration balance, and feeding frequency and schedule (NRC, 1987). Prediction equations have been developed that provide an estimate of intake for lactating dairy cows. NRC equations have been reported to significantly underestimate DMI at peak and later and to significantly overestimate early lactation DMI (Roseler et al, 1997). The best approach in practical on-farm circumstances is to always measure DMI directly. Table 11-2 provides a brief selection of DMIs for two body weights and various milk production levels.

Cows in early lactation consume less dry matter than cows at the same milk production level later in lactation. Table 11-2 thus overestimates the DMI of a cow in early lactation. This reduced DMI makes it difficult for an early-lactation cow to consume enough nutrients to support her rapidly rising production, and she loses weight (Fig. 11-1). DMI usually peaks 10 to 14 weeks postpartum, several weeks after milk production has peaked (NRC, 2001).

DMI is affected by the digestibility of the ration, particularly of the forages fed. If forages are too mature when harvested or grazed, their digestibility is reduced. These slowly digested forages are retained longer in the rumen, taking up space and inhibiting further consumption. Reduced fiber digestibility can also result if the ration contains too little rumen-degradable protein, starving the rumen cellulolytic microbes of the peptides and nitrogen they need to grow and ferment fiber. As the digestibility of the ration increases (commonly by increasing the proportion of grain fed), the DMI increases but only up to a point. Depending on the cow's milk production, there is a point at which enhanced digestibility actually reduces DMI. This point is reached when the cow can consume all her energy needs and intake begins to be regulated by energy needs, rather than by the cow's rumen fill and turnover capacity (NRC, 2001).

Feeding conditions and environment will affect intake. Hot, humid conditions (>27° C [80° F] and >80% relative humidity) will depress DMI. Mold, originating either during storage or in the bunk, decreases DMI. Important strategies to maximize DMI include maintaining adequate feeding rate from the surface of ensiled feed, avoiding spoiled feed accumulating in the bunk, and avoiding poor quality, moldy feeds.

Water

Water is an essential nutrient, although it is commonly overlooked as such (Beede, 1991). Cows consume more water than any other nutrient. A 600-kg cow eating a corn silage–based diet in a thermoneutral environment and producing 45 kg of milk per day drinks at least 140 L of water/day (NRC, 2001). On most farms, water is supplied free choice and is available most of the time. If access to water is limited, milk production falls (Little et al, 1984). Restriction of water intake has a more rapid and profound effect on milk production than restrictions on any other nutrient. Cows with uninterrupted access to fresh water drink more water than cows that have access only at certain times of the day. Along with increased water consumption, cows with unlimited access to water consume more feed dry matter and produce more milk (NRC, 1981). Cattle grazing on pasture drink two to five times per day if they have easy access to water. If water is more distant, they drink less often and consume less dry matter. Water consumption is influenced by milk production, access and competition, diet DMI, diet moisture content, environmental temperature, and the content of various minerals in the ration, particularly sodium. Water consumption increases rapidly when the ambient temperature rises above 27° to 30° C (81° to 86° F). Herd performance problems can sometimes be due to insufficient water consumption. Flow meters can be installed and used to monitor water consumption. Expected water intakes have been published (Penn State Dairy Reference Manual, 1995) and can be expected to vary between 20 and 35 gal/cow/day. Lactating cows can tolerate water of varying pH, hardness, and water temperature. Extremes of any of these factors can create problems.

The simplest and most effective approach to satisfying the cow's water needs is to provide easy, noncompetitive, free-choice access to clean, fresh water all the time. There should be at least one watering space per 20 head. A watering space is either one drinking cup or 2 linear feet of accessible trough perimeter. There should be a minimum of two separate drinking locations per group of cows to minimize the bullying effect of boss cows (Midwest Plan Service, 1985). Water flow should be designed to prevent back

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TABLE 11-2

Dry Matter Intake (DMI) in Cows in Middle to Late Lactation

Daily Yield of 4% Butterfat Corrected Milk (kg)	Dry Matter Intake			
	500-kg Cow		600-kg Cow	
	Body Weight (%)	DMI (kg)	Body Weight (%)	DMI (kg)
10	2.4	12.0	2.2	13.2
15	2.8	14.0	2.6	15.6
20	3.2	16.0	2.9	17.4
25	3.5	17.5	3.2	19.2
30	3.9	19.5	3.5	21.0
35	4.2	21.0	3.7	22.2
40	4.6	23.0	4.0	24.0
45	5.0	25.0	4.3	25.8
50	5.4	27.0	4.7	28.2
55	5.7	28.5	5.0	30.0

Adapted from the National Research Council: *Nutrient requirements of dairy cattle,* ed 6, Washington, DC, 1989 (rev), National Academy Press, Table 6-1.

siphoning of water into the plumbing system. Whatever system is used, it must be protected from freezing.

Energy

The most important aspect of any ration is to provide enough energy to meet the animal's needs. Determining the energy available in a particular feed or ration is complicated. Except under expensive research conditions, the energy content of a feed cannot be measured directly. In practice, the energy content of feed is calculated from measurements of the chemical constituents of the feed—fiber, protein, fat, and ash. The energy available from a particular feed is different depending on whether it is being used for growth or maintenance, or by a lactating cow. These differences require attention when balancing rations for growing heifers or for bulls. Fortunately, the energy metabolism for a lactating cow is similar enough for maintenance, weight gain, and lactation that one measure of a feed's energy content works for all three. That measure is net energy for lactation (NE_L) (NRC, 2001). This value discounts the energy in a feed for the digestive, absorptive and metabolic efficiencies, which are assumed to occur in its utilization. Another way to measure the energy content of feeds is to determine the total digestible nutrients (TDNs). This older system has the disadvantage in that it tends to underestimate the energy available from grains. An estimate of NE_L can be derived from TDN by this equation: NE_L (Mcal/kg) = [TDN (% of dry matter) × (0.01114) − 0.054] × 2.204 (Linn, 1989).

The lactating cow needs energy for lactation, maintenance, and growth (both for herself and for her fetus). The energy required for lactation is the energy contained in the milk produced. The cow's maintenance energy requirement depends on her level of activity and the ambient temperature. The recommended levels of energy given in Table 11-1 have been adjusted to allow for "average" activity levels. Cows forced to walk long distances or that graze on poor pastures might need as much as 20% more maintenance energy to account for the extra effort expended in "harvesting" their ration. Similarly, extremely cold weather may increase energy needs as much as 8% of a cow's total energy requirement or more. The energy needed for growth in a mature cow is the same as the energy lost during the period of weight loss in early lactation. Weight loss during early lactation contributes approximately 5 Mcal of NE_L/kg body weight loss (Moe et al, 1971). This energy must be replaced as the cow regains that weight in later lactation. Because of the increased efficiency of metabolism in lactating cows, weight gain is usually more economical when gained in late lactation rather than in the dry period. This practice also reduces the incidence of metabolic disorders in the early postpartum period that can result from overfeeding dry cows (Morrow, 1976).

The energy in the diet is derived from several sources. Carbohydrates account for between 50% and 80% of the dry matter in a cow's diet, and most are fermented to a degree in the cow's rumen. When the rumen microbes break down these carbohydrates, they produce the VFAs acetate, propionate, and butyrate. The rumen wall can absorb these metabolites. VFAs provide 50% to 70% of the cow's total energy intake. The relative proportion of these VFAS is dependent on substrate and rumen pH. When large amounts of fiber are fed, and rumen pH >6.0, acetate is the predominant volatile fatty acid produced, accounting for 60% to 70% of the total VFAs. In addition to serving the gen-

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eral energy needs of the cow, acetate is the major precursor of butterfat in milk. When higher quantities of sugars and starches are consumed, relatively more propionate is produced. Under these conditions, the milk fat content may be reduced (Linn et al, 1989).

The degree of rumen fermentation of carbohydrates depends on the material, its physical form, and the other feeds being fed. Simple sugars are almost completely metabolized, and 60% or more of starches are broken down in the rumen. Starches and sugars are more available and more fully digested if they have been processed (e.g., ground, heated, extruded) than if they are eaten as whole grains. Of the cellulose and hemicellulose in plant fiber, 30% to 50% are digested in the rumen. Fiber may be less fully used if particle size is reduced because it may escape from the rumen before the microbes have had the chance to digest it (Allen and Mertens, 1988).

Fats can make up an important part of the energy in a cow's diet. Fats have a significant advantage over carbohydrates as an energy source because they have 2.25 times as much energy per unit of dry matter. In the high-producing dairy cow constrained by DMI, this makes it possible to feed more energy without exceeding the cow's ability to eat the ration. Caution is required when feeding fats, however, because feeding more than 3% to 5% rumen available fat in the ration dry matter may be toxic to rumen microbes and interfere with rumen fiber fermentation (Chalupa and Ferguson, 1988; Palmquist, 1983). Some fats bypass the rumen, thus avoiding rumen toxicity and microbial degradation. These fats are digested in the same manner as with monogastrics.

If supplied in excess of the cow's protein needs, protein may also serve as an energy source, but feeding excess protein as an energy source may have several disadvantages. Generally, protein sources are expensive. The ammonia produced as amino acids are deaminated and must be metabolized to urea by the liver, a process that itself requires energy (Tyrrell et al, 1983). The nitrogenous waste products associated with metabolizing protein for energy may interfere with reproductive performance (Ferguson, 1988; Ferguson and Chalupa, 1989; Ferguson et al, 1988). Feeding excess protein is an inefficient and expensive way to provide energy.

There are practical limits to the energy density of lactating cow rations. Minimum levels of forage fiber are needed to maintain health and rumen function. For the highest producing cows, the energy density possible on a practical basis, without added fats, is approximately 1.72 Mcal/kg (0.78 Mcal/lb) dry matter. It is difficult to formulate rations that are more energy dense than this without reducing the fiber content of the ration below minimum levels. For high-producing cows that demand more energy-dense rations, fats must be fed, often in a form that bypasses the rumen. Saturated fats (animal sources) are generally preferable to unsaturated fats (vegetable sources). Vegetable fats in whole raw oil seeds (whole cottonseed, whole soybeans) are an exception to this generality. Whole oil seeds may tend to bypass ruminal degradation, releasing their fats only as they are digested in the abomasum and intestines.

Cows in the first 3 weeks of lactation may need to be introduced to the energy-rich ration slowly, allowing time for rumen adaptation to the diet. Feeding a small portion of the lactating cow ration to cows in the last 7 to 14 days prior to calving may help with this acclimation process. Such advanced feeding of lactating cow rations to dry cows is not without risks. If not carefully managed, such programs can lead to a higher incidence of peripartum metabolic disease.

Generally, the energy needs of early dry cows (Phase 4) are easily met. More commonly, overfeeding dry cows is the problem. Grain intake in dry cows should be restricted. High-energy forages such as corn silage should also be limit-fed to avoid overconditioning dry cows. During phase 5, the transition period, energy needs of the dry cow may be difficult to achieve because of a decline in DMI (Grummer, 1995). The challenge can be similar to rations for high producing dairy cattle—maintaining adequate energy intake during a period of lower DMI.

Energy Calculation

As suggested earlier, in most cases the direct measurement of the energy available within a feed to the animal is expensive and difficult experimentally. Empirical relationships between various components of feedstuffs and energy have been observed and are frequently used to estimate energy content. Many laboratories calculate energy of a feed based on a correlation between acid detergent fiber (ADF) and energy. The ADF content is measured and a series of equations (depending on the specific feedstuff, geographic location, maturity, and species) are used to estimate the energy available (NRC, 2001). An alternative method has been developed which is believed to be more accurate, particularly for nontraditional feeds such as by-products or high fat products. This method incorporates measurements of protein, carbohydrate fractions, indigestible carbohydrate and protein (lignin bound), and fat. Energy value of the feed is then predicted based on the known energy of these constituents (Weiss, 1993). This method is based on known conceptual relationships and should be more applicable to a wider variety of feeds than the ADF correlation. It remains to be seen if it will prove to be more accurate and effective in the field.

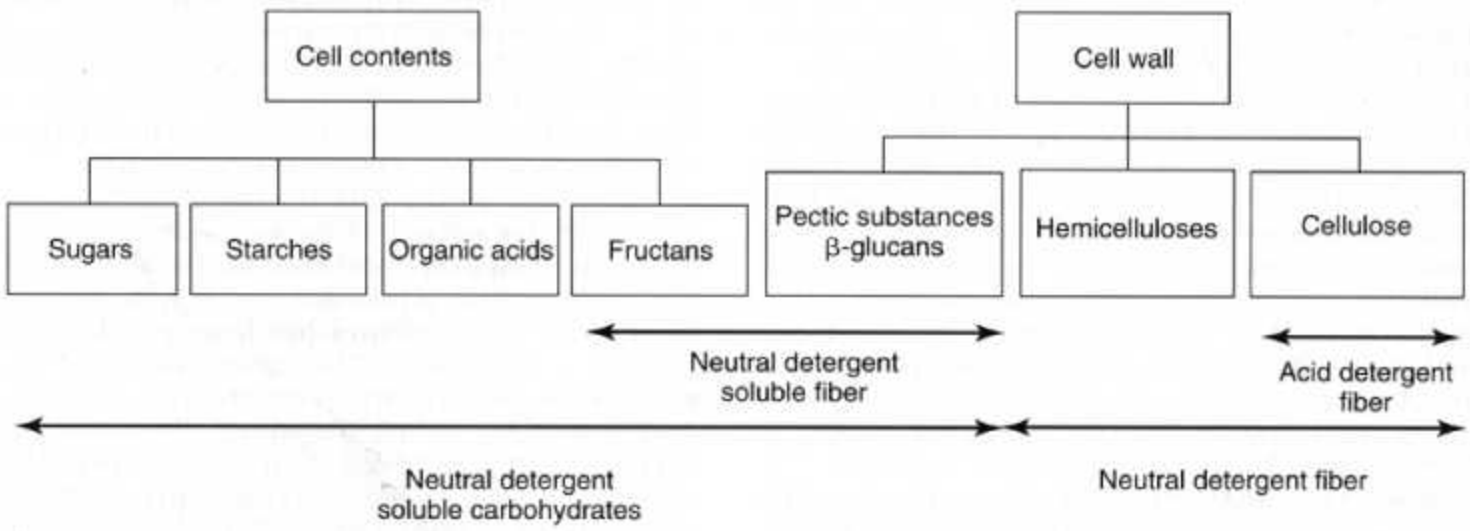

FIG. 11-2 Plant carbohydrates.

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but it is being widely used and is consistent with more recent publications (NRC, 2001).

In all considerations of feed energy values it is important to recognize that the availability of energy from a feed is a dynamic value. It is affected by the efficiency of VFA production and absorption of the specific feedstuff in the rumen, which in turn is affected by interactions with other feed items in the diet, and such factors as plant maturity, rumen pH, rumen turnover and rumen passage rate. It is affected by the metabolic state of the animal and its efficiency of utilization of various end products of digestion for a variety of metabolic fates. Although assignment of a particular "energy concentration" to a particular feedstuff has proved to be a powerful ration balancing tool, remember that it is a potentially highly variable number and can be influenced by a variety of interactions.

Fiber and Ration Carbohydrates

The makeup of the carbohydrate fraction of the dairy cow's diet is critical for optimizing both health and performance. The carbohydrates are derived from plants and contain the entire plant—both structural and nonstructural, and both cell wall and cell contents. The cell wall constituents provide the plant with its structural support and contains cellulose, hemicellulose, and lignin. It closely, although not precisely, corresponds to the fraction referred to as NDF. Lignin is contained in the NDF fraction but is not a true carbohydrate. The cell contents roughly correspond to the nonfiber carbohydrate (NFC) fraction, also described as nonstructural carbohydrate (NSC). A more accurate term would be neutral detergent soluble carbohydrate (NDSC). The correspondence with cell wall and cell contents is not exact. A diagram clarifying the various carbohydrate fractions that make up the NDF and NDSC is shown in Fig. 11-2. There is an absolute necessity to provide adequate digestible NDF to support a population of cellulolytic and other fiber-digesting bacteria in the rumen. If inadequate cellulolytic bacteria are maintained, the ability of the dairy cow to efficiently utilize fibrous feeds suffers. In addition to the fact that fiber provides a large proportion of the energy in the diet, dairy cows have an absolute need for a certain fiber content. Adequate fiber content is necessary for optimizing digestibility of the ration, maximizing DMI, maintaining butterfat levels in the milk, stabilizing the ecosystem of the rumen, and preserving the health of the cow (Allen, 1995). Many metabolic diseases can be traced to inadequate fiber levels in a cow's ration at some stage of lactation, including indigestion and rumen acidosis, lameness, abomasal displacement, milk fat depression, ketosis, and fat cow syndrome. Table 11-3 provides guidelines for the optimal NDF content of dairy rations.

As the fiber level of a feed or ration increases, the energy content decreases. The fiber level in a ration also correlates with total feed intake. If too much NDF or fiber is fed, the NDSC fraction is necessarily reduced. The NDSC fraction, particularly sugars, starches, and fructans, ferment more rapidly, producing more VFAs. This permits more rapid microbial growth. Higher milk production is thus favored by a higher proportion of NDSC in the diet, provided that not so much is fed that acid production becomes excessive and rumen acidosis results. Rumen acidosis has detrimental affects on cow health and reduces the population of fiber digesting bacteria. Fiber content can be calculated directly from measurements taken in feed testing laboratories. There are three commonly used measures of the fiber in the diet. The oldest, crude fiber (CF) is still the legally reported fiber level required on feed labels. It is inadequate for estimating either energy levels or DMIs. ADF is a better indicator of digestibility (Van Soest et al, 1978; NRC, 2001). NDF is the better measure when predicting total DMI from a particular ration (NRC, 1989). The digestibility of fiber also depends on the other components of the diet. In particular, there must be adequate rumen-available peptides and ammonia nitrogen to promote the growth of the microbes that ferment the various carbohydrate fractions of a feed (Sniffen and Robinson, 1987). Inadequate rumen-available protein reduces the rate and extent of fiber digestion.

As plants mature, their fiber content increases, particularly the lignin fraction. The plant's digestibility and energy content thus decrease with advancing maturity. The content of other nutrients decreases as well. This process is accelerated as the plant shifts from vegetative growth to seed formation. Although total dry matter yield per acre may increase, total

TABLE 11-3

*Optimum Levels of Net Energy for Lactation (NEL), Neutral Detergent Fiber (NDF), and Acid Detergent Fiber (ADF) for Dairy Cow Rations**

Milk Production (kg)	NEL (Mcal/kg)	NDF (% DM)	ADF (% DM)
<14	1.43	45	31
14-21	1.52	39	28
21-29	1.63	33	24
>29	1.74	27	21
Early dry cow	1.34	49	34
Late dry cow	1.54	33	24

From Sniffen CJ: Balancing rations for carbohydrates for dairy cattle. In *The application of nutrition in dairy practice,* Proceedings of a Symposium of the Dairy Production Medicine Group, Veterinary Learning Systems, Trenton, NJ, 1988, pp. 25-35.
*For a 600-kg cow, NDF and ADF as percentages of ration dry matter.

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feed value decreases as a crop becomes fully mature. Hays and haylages should be cut in the prebloom stage (Jorgensen, 1988). If cut for forage, small grains should be harvested at the boot stage, before the grain reaches a soft dough stage. Corn silage should be harvested by the dent stage (kernels dented), when the milk line is between one half and two thirds of the way down the kernel (Linn et al, 1989). The central failure of many dairy farm feeding programs is that the farmer harvests the forages too late. No amount of clever ration balancing can completely overcome poor forage in a cow's diet.

Formulation guidelines to ensure adequate dietary fiber have changed over the years. At one time ADF was preferred as the measure of fiber adequacy. Most nutritionists now use NDF or forage NDF as their primary criterion in establishing fiber requirements. A minimum amount of forage is also frequently recommended, regardless of fiber concentrations. In addition to the chemical composition of the fiber in a feed, the physical form of the fiber is also important (Woodford and Murphy, 1988). The length of the fiber (effective fiber or roughage value) must be long enough that it forms a floating mat in the rumen. This mat of long fiber traps smaller particles and promotes thorough fermentation of all ration constituents. Long fiber is eructated and chewed, encouraging saliva production and rumen buffering. If fiber levels in a ration are too low (and sugars and starches are too high), the rumen pH may fall below 6.0, reducing fiber digestion (Hoover, 1986). At least 50% of the forage should have a fiber length of 2.5 cm or greater (Linn et al, 1989). Silages should be cut coarsely, although there is a tradeoff between the feeding value of having coarse silages and the ease of handling and properly ensiling of more finely chopped silages. Silages should be chopped so that the theoretic length of cut is between 0.6 and 1.2 cm (Linn et al, 1989). A series of screens have been used to divide a diet or feed into fractions of various particle lengths (Penn State Forage Particle Separator). The percentage of the feed or feeds by weight found on each screen can then be calculated and graphed, giving an indication of relative particle length. This has proved to be a useful tool for evaluating particle length for a forage or a TMR. Guidelines for the percentage of particles greater than 19 mm (the coarsest screen) are presented in Table 11-4 (Lammers et al, 1996). Other methods of estimating particle size have been published (American Society of Agricultural Engineers, 1993; Ruppel et al, 1995) Recommendations for particle size should be tied to the method used for evaluation.

TABLE 11-4

Recommended Amount of Course Particles Retained on Screen with the Penn State Forage Particle Separator

Sample	Particles Retained on 19-mm Screen (%)
Corn silage (≤50% of forage)	2-4
Corn silage (>50% of forage)	10-15
Haylage (upright silo)	10-15
Haylage (bunker silo)	15-25
Total mixed ration	6-10

The optimum level of fiber in a cow's diet varies with the size of the cow, her level of production, timing of feeding, and the sources of fiber in her diet (NRC, 1989, 2001). Table 11-3 provides guidelines for fiber and energy in dairy cow rations (Sniffen, 1988). With conventional feeding programs in North America—with alfalfa and/or grass and corn silage as the primary forage sources and starchy concentrates such as corn or barley—suggested guidelines are 28% to 30% NDF with 21% to 23% NDF from forage. Forage should provide a minimum of 40% of the ration dry matter (with low quality, higher lignin forages) and a larger percentage of the diet as quality and intake increases. Use of by-product feeds may change the optimum blend of forages and concentrates in the diet. By-product feeds such as beet pulp, citrus pulp, brewer's grains, or cottonseed are high in NDF, but they are generally higher in carbohydrates such as fructans and pectins than forages and low in starch and sugars. Their NDF ferments more rapidly than most forages, but slower than starches and sugars in conventional grains. A higher NDF diet can be fed with these feeds—with less forage—provided starch and sugar levels are reduced compared to conventional diets. A minimum level of forage should continue to be fed, but that minimum level has not been well defined experimentally or in the field. Recent research has focused on methods by which the fiber requirement can be more accurately and precisely predicted across a variety of diets and feedstuffs (Mertens, 1997). Physically effective fiber (peNDF) has been suggested as a more accurate method of describing the fiber requirement. Physically effective NDF is defined as the amount of time a cow chews her cud per unit of NDF in the diet, in relation to a standard of long grass hay. It is closely tied to saliva production and can be measured directly. It is influenced by the particle size and physical form of the diet as well as the chemical composition. Physically effective NDF should be tied more closely to optimizing rumen function and health than other adjustments. Minimum values suggested in the diet to optimize rumen pH are ~22%. An alternative method of estimating peNDF has been suggested. A standard dietary concentration of 30% NDF has been set as a base requirement. Adjustments above or below this number, determined by such factors as forage particle length, degradability of carbohydrate sources, and frequency and pattern of feeding the diet, can then be made to ensure adequate fiber for optimum rumen function (Allen, 1995). Although similar to practical adjustments made in the field, experimental trials tying these adjustments to cow performance are limited.

Balancing the relative amounts of carbohydrates supplied to the rumen including sugars, starches, pectins, and NDF; providing adequate particle length to maintain the rumen floating fiber mat; and ensuring optimum fiber digestion are all important to avoid rumen acidosis and to maintain optimum production and herd health.

Protein

Protein is one of the most expensive constituents of the dairy cow's diet. The requirement for "protein" (nitrogen) in dairy cow rations is really a requirement for amino acids absorbed from the intestines. These amino acids are derived from two sources: digested protein that escapes degradation in the rumen and microorganism protein from bacterial and protozoal protein synthesis in the rumen (Fig. 11-3). True protein in the diet has one of two fates. Some protein is degraded into amino acids and nonprotein nitrogen (ammonia and other nitrogenous compounds). These sources of nitrogen are used by the rumen microbes for their own protein

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synthesis. Nonprotein nitrogen sources in the diet (e.g., ammonia, urea, nitrates, and others) are also used for protein synthesis through the same pathways. The ability of the rumen microbes to incorporate nonprotein nitrogen into microbial protein is limited by various factors, such as the type, amount, and rate of fermentation of energy sources and the rate of passage of rumen contents (Chalupa and Sniffen, 1991). The energy in fats is not used in microbial protein synthesis, although there may be a direct requirement of rumen bacteria for a small amount of free fatty acids (Spartan Ration Evaluator, 1992). If a significant portion of the ration's energy content is from fats (and therefore not carbohydrates), then more of the protein must bypass the rumen. Otherwise the protein degradation products formed in the rumen lack available energy for microbial synthesis and are lost in the urine (Chalupa and Ferguson, 1988). Protein not degraded in the rumen (bypass protein, escape protein) is either digested along with the microbes in the abomasum and intestine, as in a monogastric, or else passes unabsorbed in the feces.

The rumen microbes cannot synthesize enough protein to support high levels of milk production in the lactating cow. Dairy cow diets require that some of the protein escape degradation and bypass the rumen. In a typical diet, approximately 40% of the protein eaten must be true protein that escapes degradation, whereas 60% of the protein value can be a mixture of protein and nonprotein nitrogen that is degraded and incorporated into rumen microbes (NRC, 2001; Chalupa and Sniffen, 1991). The degradability of a particular protein depends on the type of feed, method of processing (e.g., grinding, heating, drying, extrusion, pelleting), schedule of feedings, and other constituents of the diet. In the final analysis the cow's nutrient needs are for absorbed amino acids, not simply protein. For many years, protein nutrition in monogastrics has evolved in the direction of describing nutrition requirements not in terms of protein but of specific amino acids. While in ruminants the physiology at the tissue level is similar, describing requirements in terms of amino acids has proved to be much more difficult and complex. This is primarily due to the changes in digestive products presented to the stomach and intestine because of fermentation in the rumen as well as the difficulty in measuring those changes.

Nonetheless, experimental models and methods have been developed that have attempted to identify limiting essential amino acids in ruminant systems, particularly in milk production. Production should respond to supplementation with the limiting amino acid(s). They must be provided in a manner that results in their delivery to the tissues, without confusing any effects of the amino acid(s) with the microbial mass and undegraded intake protein already present in the diet. Several different experimental approaches have been used in determining the first limiting amino acids and the response to them. These experimental approaches include (1) infusion of amino acids directly into the bloodstream and measurement of extraction efficiencies by the mammary gland and response; (2) abomasal or duodenal infusion of amino acids and measuring response; and (3) calculation of amino acid requirements by the factorial method, including product composition and metabolic transfer efficiencies, and then comparing that with estimated or measured amino acid composition of duodenal contents and evaluating response. All three approaches have led to reasonably consistent results, providing some degree of confidence in the accuracy of these results. (See Erasmus, 1999 for review.) On conventional diets,

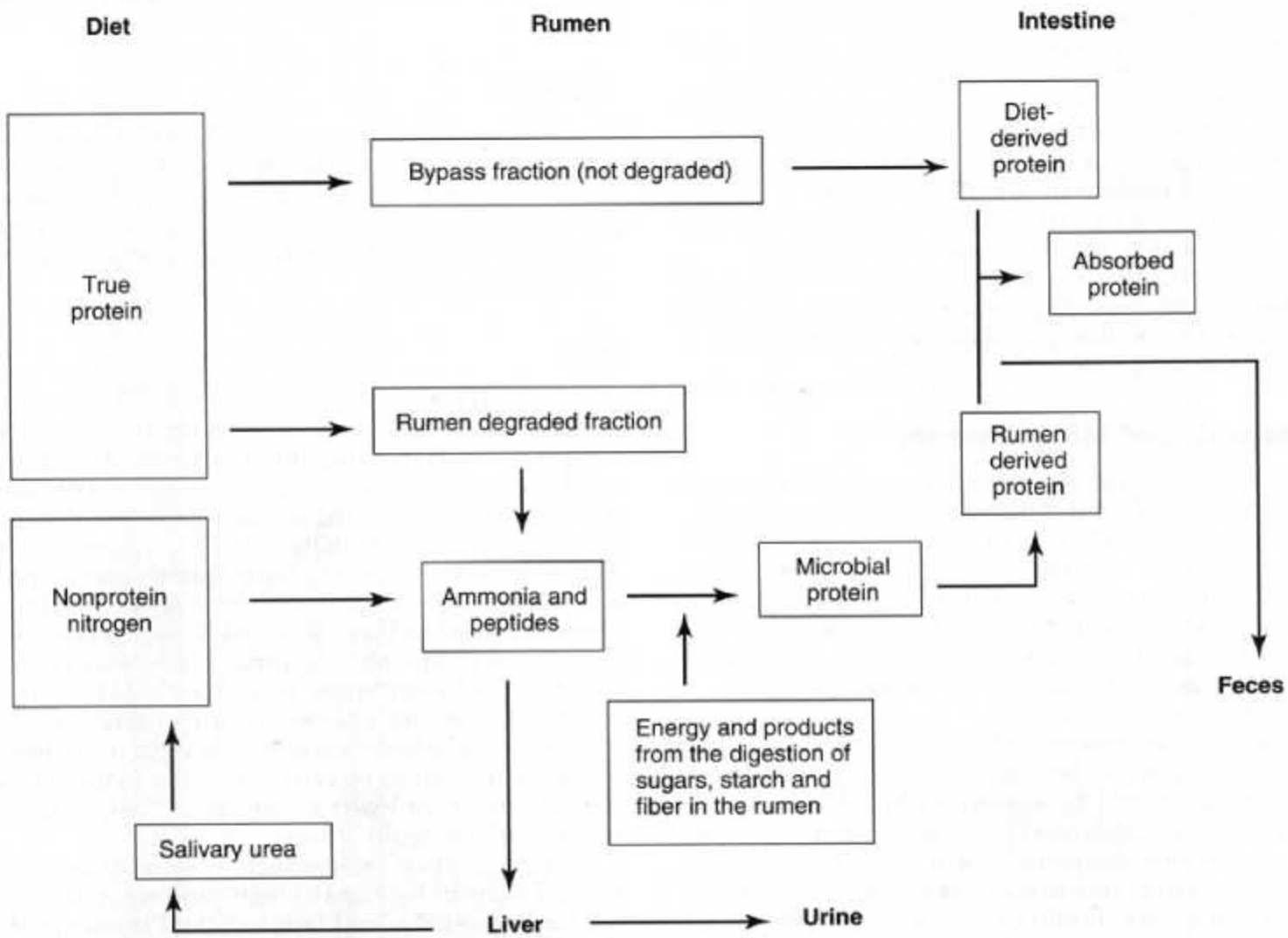

FIG. 11-3 Protein and nitrogen use in the dairy cow.

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lysine and methionine are usually considered the first two limiting amino acids for milk production, with lysine frequently considered first limiting on corn-based diets, and methionine perhaps first limiting on other common diets. Approximately 15% of the essential amino acids from microbial production and bypass sources should be lysine and 5% methionine. Similar results are obtained using both the factorial calculations and dose response studies. Feeding trials using encapsulated lysine and methionine treated to prevent rumen degradation, yet permit intestinal digestion, have tended to validate these predictions (Armentano et al, 1997). In early lactation the response is frequently increased production of milk. After peak, the response is usually an increased milk protein percentage. An increased milk response is rarely observed with supplemental lysine and/or methionine after 120 days in milk of lactation. In addition, a decline in milk yield has been observed if methionine is supplemented without first meeting the lysine requirement (Robinson et al, 1996).

Protein quality in terms of its ability to support milk production is highly variable. A comparison of the amino acid profiles of milk and a variety of protein sources is shown in Table 11-5. The amino acid composition of microbial protein is very close to ideal for milk production. Unfortunately, the quantity of microbial output is sufficient to supply the protein needs for only 60 to 70 lb of milk production. High-producing cows require additional essential amino acids from bypass protein. Of commonly used supplements, it can be seen that only fish meal comes close to approaching microbial protein in quality for use in supporting milk production, based on amino acid composition. In a recent review of multiple feeding experiments, replacement of degradable protein with more undegradable protein sources rarely improved milk production or milk protein percentage. The consistent exception appeared to be when fish meal was the source of undegradable protein, in which case there was a positive response to undegradable protein supplementation (Santos et al, 1998). Selection of dietary ingredients based on amino acid content of the bypass component is a realistic approach to feeding dairy cattle. Selection of a blend of bypass sources to achieve a desirable amino acid profile, or supplementation of specific protected amino acids to complement the undegraded protein sources in the diet, may be the most feasible approach. It should be evident that maximizing output of rumen microbial protein, by ensuring efficient rumen microbial growth, should be the first priority when meeting the protein needs of the dairy cow.

Macrominerals and Microminerals

The total mineral content of a lactating cow's diet is a small percentage of the total DMI. Adequate mineral composition in dairy cow diets is usually easy to achieve, provided the nutrient composition of the major feedstuffs is known and accounted for during ration formulation. Supplemental minerals are widely available and should be a small percentage of the total cost of the ration. Despite these facts, imbalances, deficiencies, and excesses of various minerals are common in lactating cow rations.

The phosphorus requirement for dairy cattle is receiving intense scrutiny, primarily because of the negative effects on the environment created by excessive phosphorus supplementation. Excess phosphorus is excreted primarily through the feces, and chronic oversupplementation can lead to an excess in soils, water, and runoff (Tamminga, 1992). The current NRC guidelines should be considered to provide adequate phosphorus, in most cases, and feeding higher levels should be discouraged.

Table 11-6 summarizes some of the major roles of minerals in the cow and calf (Linn et al, 1989; NRC, 1989, 2001). The macrominerals are calcium, phosphorus, magnesium, sulfur, potassium, sodium, and chloride. Their requirements are best expressed as percentage of total DMI. The microminerals include iodine, iron, selenium, copper, cobalt, manganese, and zinc. They are needed only in minute quantities, and their requirements are usually expressed in parts per million of the diet dry matter.

Vitamins

The fat-soluble vitamins A, D, and E (Table 11-7) are all recognized as necessary additives in dairy cow diets (NRC, 1989, 2001; Herdt and Stowe, 1991). Vitamin K is usually present in common feedstuffs, is synthesized in the rumen, and does not need supplementation unless dicumarol poisoning is present from eating moldy sweet clover hay. It has been generally assumed that ruminants, including dairy cattle, do not need water-soluble vitamin supplementation because their diets are often rich in B vitamins, and that rumen microorganisms synthesize adequate amounts. It seems likely, however, that certain B vitamins should be supplemented in dairy cow rations under some conditions, including possibly niacin, choline, and thiamine (NRC, 1989). Dairy cattle can become vitamin B_{12} (cyanocobalamin)-deficient with diets inadequately supplemented with cobalt.

FEEDS FOR THE DAIRY COW

There are several broad classes of feedstuffs fed to dairy cattle: forages, concentrates, by-products, minerals, vitamins, and additives. Several excellent references are available for more information about the feeds used in dairy cow diets (Bath et al, 1998; Dale, 1998; NRC, 2001; Linn et al, 1989; MacGregor, 1989).

Forages

Forages typically make up the majority of the dry matter in a dairy cow's diet (McCullough, 1989). The major forages are hay, silages and haylages, green chop, and pasture. Most of the fiber in a dairy cow's diet is derived from forages, and in most cases a large proportion of the energy and protein also comes from forages.

Hay

Hay is dried grass or legumes (e.g., alfalfa, clover). By drying these plants to about 90% dry matter, they can be stored for long periods. Harvesting results in some loss of feed in the field and some nutrients may be lost gradually during storage (e.g., vitamin A). The quality of the hay depends significantly on the stage of maturity at harvest and the care taken in drying and storage. As plants mature, energy, protein, calcium, phosphorus, and digestibility all decline, whereas fiber increases. As these fiber levels rise, so does the proportion that is indigestible lignin and ADF. Hay is best if cut in the early, prebloom stage, and certainly before any seeds are produced. Care must be taken during harvest to avoid losing too many leaves from legumes (the most nutrient-dense part of the plant) and to be certain that dry matter is above 80% before storage. At lower dry matters, there is enough moisture to support mold growth.

Other dry plant forages such as straw or corn stover have limited value in the diets of high-producing dairy cows. They are too indigestible and lack sufficient nutrients. If fed, they should be strictly limited so that they do not reduce the cow's total DMI because of their low rate of turnover in the rumen.

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TABLE 11-5

Comparison of Amino Acid Profile of Various Protein Sources with Milk Protein Amino Acid Profile

Protein Supplement	Milk Protein Score*	Total Essential Amino Acid (%)			Apparent Limiting Amino Acid	
		Lysine	Methionine	Isoleucine	First	Second
Blood meal	0.42	15.7	2.1	2.1	Isoleucine	Methionine
Canola meal	0.68	13.1	4.8	9.3	Isoleucine	Methionine
Corn gluten meal	0.21	3.8	5.5	9.3	Lysine	Tryptophan
Corn distillers with solubles	0.32	6.2	5.2	9.8	Lysine	Tryptophan
Cottonseed meal	0.46	9.6	3.8	7.7	Methionine	Isoleucine
Dried brewer's grains	0.40	11.4	4.8	10.6	Lysine	Methionine
Feather meal	0.19	3.9	2.1	10.0	Histidine	Methionine
Fish meal	0.75	17.0	6.3	9.3	Leucine	Tryptophan
Meat and bone meal	0.43	14.2	3.6	7.8	Tryptophan	Isoleucine
Soybean meal	0.46	13.7	3.1	10.8	Methionine	Valine
Sunflower meal	0.62	8.6	5.4	10.1	Lysine	Leucine
Rumen microbial protein	0.78	16.5	5.0	11.5	Histidine	Leucine
Milk	1.00	16.0	5.5	11.4	—	—

*Amino acid content of most limiting amino acid relative to milk protein.

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TABLE 11-6

Minerals in Dairy Rations

Mineral	Function(s)	Clinical Abnormalities	Feed Sources for Dairy Cattle	Recommended Levels for High-Producing Lactating Cows
Calcium (Ca)	Bone and teeth formation; blood clotting; muscle contraction; 0.12% in whole milk	Rickets; slow growth and poor bone development; easily fractured bones; reduced milk yield; milk fever	Alfalfa and other legumes; ground limestone; dicalcium phosphate; steamed bone meal	0.66% DMI* (0.8% with added fat)
Phosphorus (P)	Bone and teeth formation; energy metabolism, part of DNA and RNA; 0.099% in milk	Fragile bones; poor growth; low blood P (less than 4-6 mg/100 ml); depraved appetite (chewing of wood, hair, and bones); poor reproductive performance	Monosodium, monoammonium and dicalcium phosphates; steamed bone meal; cereal grains; grain by-products; oilseed meals	0.41% DMI* (0.48% in early lactation)
Sodium (Na)	Acid-base balance; muscle contraction; nerve transmission	Craving for salt; reduced appetite; if severe, incoordination, weakness, shivering, and death	Common salt and buffer products	0.18% DMI
Chlorine (Cl)	Acid-based balance; maintenance of osmotic pressure; manufacture of hydrochloric acid in abomasum	Craving for salt; reduced appetite	Common salt and commercial supplements	0.25% DMI
Magnesium (Mg)	Enzyme activator; found in skeletal tissue and bone	Irritability; tetany; increased excitability	Magnesium oxide; forages and mineral supplements	0.25% DMI (0.3% with added fat)
Sulphur (S)	Rumen microbial protein synthesis, especially when nonprotein nitrogen is fed; found in cartilage, tendons, and amino acids	Slow growth; reduced milk production; reduced feed efficiency	Elemental sulfur, sodium and potassium sulfates; protein supplements; legume forages	0.20% DMI

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Potassium (K)	Maintenance of electrolyte balance; enzyme activator; muscle function; nerve function	Decrease in feed intake; loss of hair glossiness; lower blood and milk potassium	Legume forages; potassium chloride; potassium sulfate	1.00% DMI
Iodine (I)	Synthesis of thyroxine	Big neck in calves; goitrogenic substances may cause deficiency	Ionized salt, trace mineralized salt, and commercial supplements	0.60 ppm DMI
Iron (Fe)	Part of hemoglobin; part of many enzyme systems	Nutritional anemia	Forages; grains; trace mineralized salt and commercial supplements	50 ppm DMI
Copper (Cu)	Needed for manufacture of hemoglobin; coenzyme	Severe diarrhea; abnormal appetite; poor growth; coarse, bleached, or graying hair coat; osteomalacia	Trace mineralized salt and commercial supplements	10 ppm DMI
Cobalt (Co)	Part of vitamin B_{12} needed for growth of rumen microorganisms	Failure of appetite; anemia; decreased milk production; rough hair coat	Trace mineralized salt and commercial supplements	0.10 ppm DMI
Manganese (Mn)	Growth; bone formation; enzyme activator	Delayed or decreased signs of estrus; poor conception	Trace mineralized salt, and commercial supplements	40 ppm DMI
Zinc (Zn)	Enzyme activator; wound healing	Decreased weight gains; lowered feed efficiency; skin and hoof problems; slow healing wounds	Forages; trace mineralized salt, and commercial supplements	40 ppm DMI
Selenium (Se)	Antioxidant; needed for red blood cell glutathione peroxide enzyme	White muscle disease, unthriftiness, retained placenta, elevated milk somatic cell counts	Trace mineralized salt, and commercial supplements	0.30 ppm DMI

Adapted from Linn JG, Hutjens ME, Howard WT, et al: *Feeding the dairy herd,* St Paul, Minn, Minnesota Extension Service University of Minnesota, 1989, North Carolina, North Central Regional Extension Pub No 346.
DMI, Dry matter intake.

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TABLE 11-7

Fat-Soluble Vitamins in Dairy Rations

Vitamin	Functions	Clinical Abnormalities	Common Feed Sources for Dairy Cattle
A	Essential for normal vision, cellular function, and maintenance of epithelial linings of respiratory, reproductive, and digestive tracts	Night blindness; skin problems; blind, dead, or weak calves; reproductive problems	Sources of carotene: green, leafy forages; hays; haylages (little weathering) unfrosted corn silage; synthetic A; vitamin premix; fish liver oil
B	Normal bone growth and development; mobilization of calcium, and phosphorus	Rickets, osteomalacia	Sun-cured forages; fish liver oils; synthetic premixes
E	Antioxidant; associated with selenium	Oxidized flavor in milk; muscle problems; white muscle disease; cardiac muscle abnormalities	Alfalfa; germ of cereals; wheat germ oil; cereal grains; synthetic premixes
K	Required for blood clotting	Hemorrhaging; moldy sweet clover disease	Green, leafy forages; ample amounts normally are synthesized in the digestive tract

Adapted from Linn JG, Hutjens MF, Howard WT, et al: *Feeding the dairy herd*, St Paul, Minn, Minnesota Extension Service, University of Minnesota, 1989, North Carolina, North Central Regional Extension Pub No 346.

Silages and Haylages

Silages are forages with somewhat higher water content than hays (25% to 50% dry matter). These feeds are harvested and then packed in some sort of storage container (e.g., upright silo, trench silo, plastic bags) in which there is limited oxygen. The sugars and starches in the forage are fermented anaerobically until the acidity rises to high enough levels that it serves as a preservative (ensiling). Silages can be stored for extended periods without significant spoilage as long as they are protected against oxygen. Quality of silage fermentation is a critical factor in ensuring a nutritional, palatable feed. It can be affected by a variety of factors, including moisture, packing, availability of substrate, environmental temperature, and additives.

In recent years, plant breeders have begun to pay attention to qualities that enhance suitability as silage. Particularly with corn, but also with small grains and alfalfa, selection of specific varieties according to their suitability as silage is now practical and feasible.

Corn Silage

If cut at the right stage, corn silage is an excellent dairy feed. It can be as much as 50% grain on a dry matter basis and can supply a large proportion of the cow's energy needs. Corn silage must be supplemented with protein and minerals to balance a ration for a dairy cow. Corn should be harvested for silage when the ears are fully mature and the tops of the kernels have begun to dent. The "milk line" visible on the kernel should be one half to two thirds of the way down the kernel. At this stage the corn is approximately 30% to 35% dry matter. Silages harvested at earlier, wetter stages yield less dry matter per acre and tend to lose nutrients by seepage once ensiled. Drier, more mature corn makes silage that is less digestible, is harder to pack in storage, and is thus more accessible to oxygen and more prone to molding. In recent years, corn plant breeders have focused on developing corn varieties specifically for use as corn silage. Mechanical processors that increase the availability of energy from the ensiled corn plant have also been developed.

Legume and Grass Haylages

If legumes and grasses are harvested and stored at higher water contents than hay (30% to 50% dry matter), they can also be ensiled. Haylages offer an advantage over hay in that they can be stored sooner after cutting, reducing the risk of rain damage during the drying process. Haylages usually suffer less leaf loss during harvest and commonly require less labor both during and after harvest than hay. Alfalfa haylage is the most common haylage. It is a palatable, high-protein, highly digestible source of nutrients while also providing needed fiber in the ration. Alfalfa should be cut in the prebloom stage of growth for best use in the rations of high-producing dairy cows. Haylages should be chopped reasonably coarsely (1 to 1.5 cm theoretic length of cut) so that they pack and ensile properly while still stimulating cud chewing and proper rumen fiber mat status. In bunker silos, good preservation with a longer theoretical cut can be achieved.

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Grasses can also be ensiled, including small grains such as rye, oats, triticale, barley, or wheat. The stage of maturity at harvest and care in storage are critical to the success of small grain silages. It is recommended that they be harvested in the "boot" stage of maturity. Sorghum can also be ensiled. Its properties as a forage fall between those of corn silage and grass haylage.

Green Chop

During the appropriate seasons, forage plants (e.g., legumes, grasses) may be cut and fed directly as green chop to the milking cows without drying or ensiling. These feeds are usually palatable and can be good sources of digestible nutrients if cut at the right stage of maturity. If green chop is too wet or is a large proportion of the total ration, its bulk may reduce total DMI. It may be difficult to monitor DMI and to balance other needed nutrients when feeding green chop, because the dry matter content of the green chop can vary widely. Green chop spoils quickly and feed bunks must be cleaned daily to avoid moldy feed. Feeding green chop to high-producing dairy cows must be managed expertly, but it remains a very inexpensive method of harvesting and feeding forage.

Pasture

Pasture has many of the same advantages and disadvantages as feeding green chop. It has the added advantages of needing no harvesting, providing exercise and a clean environment to the cows, and reducing the need for manure management. It has the disadvantages that bad weather can make the pasture a dirty and inhospitable place for the cow and that cattle must be brought in twice daily to be milked. Even with its disadvantages, grassland feeding systems are the basic structure of much of the world's dairy industry.

Grassland dairying tends to be more seasonal than dairying in which all feeds are brought to the cow. Calving and lactation must be timed to take advantage of seasons with the greatest grass growth. Pasture management is of paramount importance, including fertilization, pasture rotation, water for the cattle and for irrigation, and selection of grass and legume varieties on the pasture. In extremely wet regions the cows themselves may churn up large proportions of the land, thus reducing total forage production per acre. Levels of milk production are typically lower on pasture-based dairies. Despite all these difficulties, pasture is still the most efficient means of milk production in some regions, particularly because pasture commonly offers lower feed and labor costs.

Relatively recent advances in fencing and watering technology have improved the ability to manage pastures in smaller subdivisions. A precise matching of herd needs with forage production is thus possible by more intensive rotation of smaller paddocks for the herd. This system is referred to as management intensive grazing (MIG) or intensive rotational grazing (IRG). Better forage quality, more productivity per acre, and greater profitability would characterize an intensively managed pasture system versus one that was not managed intensively. Selection of plant pasture species varies according to geographic location and soil type, but a legume-grass mixture is frequently a suitable combination for best growth during varied day length and moisture conditions. The number of North American dairies adopting a more intensive pasture program for at least some of their forage requirements is increasing, primarily for economic reasons. When compared with conventional systems, intensively managed pasture systems have consistently been more profitable (Schraufnagel et al, 1998; Dartt et al, 1999).

Grains

The major role of grains is to provide energy in the diet. Some grains are also moderately high in protein. The energy in the grain is mostly in the form of sugars and starch. The digestibility of grains is commonly increased by processing, either by making the contents more accessible to rumen bacteria (e.g., by rolling, grinding, or cracking) or by also changing the structure and digestibility of the starch (e.g., by steaming, extrusion, popping, heat drying, pelleting, or flaking). If grains are overprocessed (ground too finely), they may be broken down too rapidly, with an increased risk of rumen acidosis. Grains are digested at different rates. Roughly, wheat is most rapidly broken down in the rumen, followed by barley, oats, corn, and sorghum (Sniffen, 1988). Careful feed management is necessary when feeding grains so that the proper rumen environment and buffering are maintained and acidosis is avoided.

Corn

Shelled corn or ear corn is the most commonly fed grain. Ear corn (which includes the cob) has about 10% less energy than shell corn (kernels only) but is higher in fiber. It is commonly the least expensive grain available for dairy rations.

Barley

Barley is a good source of energy and protein. It should be rolled, not ground, in dairy rations.

Oats

Lower in energy and higher in protein than corn, oats may help maintain rumen function because of their higher fiber content and slower digestion in the rumen.

Wheat

Because of its cost, wheat is used less often than other grains in dairy rations. It is high in energy and relatively high in protein. The starch in wheat is rapidly digested in the rumen, and in a dairy ration the amount of wheat in the diet should be strictly limited to avoid rumen acidosis.

Most grains are stored at approximately 90% dry matter. If the moisture content is higher than 12% to 15% at harvest, the grain should be dried before storage to avoid mold growth. It is possible, however, to harvest grain, particularly corn, at a higher water content and to ensile it in an anaerobic environment. If stored in an airtight silo or bag, corn can be stored whole. In conventional silos it should be ground before storage. Such "high-moisture corn" (70% to 75% dry matter) has several advantages (Linn et al, 1989):

1. Corn can be harvested 2 to 3 weeks earlier, reducing the risk of crop loss if the fall weather suddenly turns bad.
2. Drying, storage, and handling costs may be reduced.
3. The need for frequent grain processing (e.g., grinding, rolling) is reduced.
4. The palatability of the corn is improved.

Protein Supplements

Protein supplements are concentrated sources of protein or nitrogen. They are derived from four major sources: oil seeds (e.g., soybeans, peanuts, sunflower seeds, flax, cottonseed), grain processing and fermentation by-products (e.g., corn gluten meal, distiller's dried grains), animal products (e.g., meat and bone meal, blood meal, fish meal, feather meal), and nonprotein nitrogen sources (e.g., urea). This category

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of feeds overlaps with the by-product feeds (see later discussion). Several common protein supplements are used. In the selection of a specific protein source, several criteria should be used. These include: the profile of the protein source compared with what is needed in the diet (i.e., the fraction of degradable and undegradable protein that is supplied by that protein source); the amino acid profile of the bypass fraction of the protein compared with the needs of the animal and the other sources in the diet; and cost, both per unit of protein and unit of bypass protein, if that is the most limiting nutrient.

Soybean Meal

Soybean meal is the most commonly used source of supplemental protein in dairy cattle diets. The protein in soybean meal is relatively degradable in the rumen. Similar to whole soybeans, the amino acid profile of soybean meal is relatively high in lysine and low in methionine, compared with the essential amino acids required for milk production. The most commonly used soybean meal is 44% protein, as fed. Soybean meal derived from dehulled soybeans (48% protein) is also commonly available. Most commercial dairy concentrate mixes contain soybean meal.

Soybeans

Whole soybeans can be fed in dairy cow diets. Beans can be fed raw, roasted, or extruded. Roasting and extrusion increase the proportion of soy protein that bypasses rumen degradation and increases palatability. Soybeans contain approximately 18% fat. Because of the rumen's limited ability to digest vegetable fats, only a limited amount of soybeans can be fed. Raw soybeans also contain urease, an enzyme that breaks down urea. They should not be fed when urea is included in the diet.

Distiller's Dried Grains

Derived as a by-product of the alcohol distillation industry, distiller's dried grains are an excellent source of rumen undegradable protein and energy. The composition varies depending on the grain that was fermented for distillation. Corn is the most common grain used.

Corn Gluten Meal

Derived from the wet milling of corn for starch and corn syrup, corn gluten meal is a source of protein with low rumen degradability. It has a high energy content. Corn gluten meal should not be confused with corn gluten feed, a moderate source of relatively degradable protein. The bypass fraction of corn gluten meal is relatively high in methionine content but low in lysine.

Meat and Bone Meal, Meat Meal, Blood Meal

These feeds are by-products of abattoirs. They are excellent sources of protein, are relatively undegradable in the rumen, and may serve as important sources of limiting amino acids in dairy cow diets. They are relatively unpalatable. However, animal-derived protein sources may transmit disease, including salmonellosis. In England and other European countries, rendered meat and bone meal has been implicated as a cause of bovine spongiform encephalopathy (BSE, or "mad-cow" disease) (Gibbs et al, 1992). Feeding ruminant derived meat and meat and bone meal to cattle has been prohibited in the United States since 1997. Porcine derived meat and bone meal is still a common feedstuff in dairy cattle diets. Animal protein products tend to be higher in lysine but may be low in methionine. Fish meal is a relatively good source of both lysine and methionine, usually the first limiting amino acids for milk production.

Urea

Urea is an inexpensive and potent source of nonprotein nitrogen in dairy diets. It is rapidly converted to ammonia in the rumen and should not be fed with raw soybeans because they contain urease and can potentiate urea's toxicity. Urea contains the equivalent of 287% crude protein because of its high nitrogen content compared with true protein. It should be fed to dairy cows only if there is a deficiency of rumen-degradable, soluble protein in the remainder of the diet. If there is insufficient energy for the rumen bacteria to process the nonprotein nitrogen from urea, the potential protein value is lost and the ammonia nitrogen is processed by the liver (at an energy cost) and excreted in the urine.

By-Products

As ruminants, dairy cows can digest many feeds that are essentially indigestible for monogastrics. This means that a broad range of by-products and residues of other industries can be fed to cattle. These feeds might otherwise have no value or might add to the economy's waste disposal problems. Many of these products are only available in limited local areas, some are only seasonally available, and many require special handling, storage, and delivery arrangements. By-product feeds are often very economical and supply valuable nutrients and diversity in dairy cow diets. Some by-product feeds are cottonseeds, citrus pulp, bakery waste, potato waste, corn gluten meal and feed, distiller's dried grains, soy or peanut hulls, hominy, wheat midds, rice bran, tallow, grain screenings, tomato pomace, pea vines, meat and bone meal, brewer's grains, and beet pulp, with many other possibilities. In fact, even soybean meal is a by-product feed. It is a "residue" of the vegetable oil industry.

By-product feeding is likely to play an increasingly important role in dairy cow rations as larger herds move more and more toward blended and total mixed rations. Each by-product feed has its own special characteristics in dairy rations, nutrient profile, feeding qualities, palatability, and biologic limits on the amount that can be fed. Veterinarians who design feeding programs for their client dairies must be familiar with the by-product feeds available in their area, their costs, and their possible role in the dairies' overall feeding programs. Some by-product feeds are consistent from batch to batch (soybean meal), whereas others may vary widely depending on the batch's source, processing, and storage history. There are good sources of information about the quality control and evaluation of by-product feeds (Bath et al, 1998; Schingoethe, 1991; UMC, 1988; MacGregor, 1989; NRC, 2001).

The following are some commonly available by-product feeds. Others were described earlier (see Protein Supplements).

Whole Cottonseeds

Whole cottonseeds are a rich source of energy because of their oil content. Whole cottonseeds also are moderate sources of protein and provide some fiber in the diet. If fed whole, some of the seeds escape rumen degradation and provide bypass protein and oil that are digested after leaving the rumen. Because of the oil content and potential for gossypol toxicity, generally no more than 3.5 kg should be fed per cow per day.

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Brewer's Grains

Brewer's grains are commonly delivered as a wet slurry from the brewery, although dry brewer's grains are also available. Brewer's grains are a reasonable source of energy and relatively high in protein. They are useful for "extending" a limited supply of corn silage on a farm. In warm weather, wet brewer's grains spoil quickly, so inventories must be turned over every few days. Because wet brewer's grains are 80% water, their bulk can reduce DMI if more than approximately 15 to 20 kg/cow are fed daily.

Beet Pulp

Beet pulp is a by-product of the sugar beet industry. It is a palatable feed, high in energy and digestible fiber.

Soybean Hulls

Soy hulls are sources of highly digestible fiber that can replace some of the starch in diets prone to rumen acidosis.

Wheat Midds

One of several similar by-products of the flour milling industry, wheat midds are a common ingredient of commercial dairy cattle feeds. They are a high-energy, moderate protein feed.

Citrus Pulp

A feed relatively high in energy and fiber, citrus pulp shares many characteristics with beet pulp. Because of its unusual flavor, it must be introduced into rations slowly to allow the cows to become accustomed to it.

Molasses

A by-product of the manufacture of sugar, molasses is used principally to reduce the dustiness of feeds and to improve palatability.

Tallow

Derived from animal fat, most commonly beef, tallow is a source of energy for dairy rations. Although much of the fat in tallow is probably inert in the rumen, it still can be used only in limited quantities because of the limits of the rumen to handle fats.

Minerals

Minerals play an obvious critical role in dairy cow nutrition (NRC, 2001; Beede, 1991). Because the total mineral intake needed by the dairy cow is such a small part of total DMI, providing adequate mineral nutrition is more a matter of paying attention to details, rather than difficulty of obtaining or providing adequate levels. Many dairy farms pay too much for minerals in their ration, buying expensive "custom" mineral mixes when simpler basic ingredients would do just as well. Like all nutrients, minerals in a cow's diet are needed in absolute amounts, not ratios. The relative balance of minerals is important (say, calcium-to-phosphorus ratio), but proper ratios of inadequate quantities are not effective. Table 11-6 outlines the major minerals needed in dairy cow diets, their functions, deficiency symptoms, and common sources for lactating cows. Dairy cows do not preferentially select feeds that balance their mineral needs. Minerals must be fed in a way that forces cows to consume adequate amounts, usually by blending the minerals with the grain mix or as part of a TMR.

Vitamins

Vitamins, like minerals, are easily included in dairy cow diets if attention is paid to details. The fat-soluble vitamins are typically added to dairy cow diets at levels that satisfy the total requirements, ignoring any possible contribution of vitamins present in the forages or concentrates (Table 11-7).

Additives

Additives are materials added to rations for a variety of reasons that enhance performance. They fall into many categories—some nutritive, some not. Whether a particular additive is desirable depends on many factors, including price, production effect, specific factors on the farm, and others (Hutjens, 1986, 1991). Many of the additives pushed onto farms by enterprising salespeople are of little or no value to the producer. Some of the commonly used additives follow, and there are many other additives beyond those mentioned. Other sources have presented more extensive discussions (Hutjens, 1986, 1991; Linn et al, 1989).

Buffers or Alkalinizing Agents

There are several compounds that serve as buffers or alkalinizers for dairy cattle. Through moderation of the acidity resulting from high-concentrate diets, these compounds preserve a hospitable environment for cellulolytic bacteria in the rumen. This effect helps maintain rumen and cow health and, by enhancing fiber digestion, preserves normal butterfat levels in the milk. Sodium bicarbonate is the most widely used buffer. Magnesium oxide is also commonly added as an alkalinizing agent and as a source of magnesium. The effect of magnesium oxide is enhanced if used in concert with sodium bicarbonate. Other buffers or alkalinizing agents used in dairy diets are sodium sesquicarbonate, and calcium carbonate. Most buffers are unpalatable and must be blended with other feeds to be consumed. Cows cannot be depended on to consume adequate levels of buffers free choice. Buffers are usually added at the level of 0.1 to 0.2 kg/cow/day.

Niacin

The B vitamin niacin has been shown to have positive effects when fed to high-producing cows in negative energy balance (early lactation). Although not consistently effective on every farm, added niacin on some farms can increase milk production in those stressed, early-lactation cows. Niacin is too expensive to be fed to all cows routinely.

Ionophores

Monensin, decoquinate, and lasalocid are ionophore antibiotics that alter metabolic patterns in the rumen. When added to the rations of growing heifers, the rates of growth and feed efficiency are improved. They should be recommended for most youngstock rations. They are not approved for use in lactating dairy cattle in the United States. In Canada, monensin has been approved for lactating cattle as an aid in the treatment and prevention of ketosis. The recommended level is approximately 300 mg/head/day.

Yeast and probiotics

Many direct fed microbials have been marketed and researched as additives for dairy cattle. They include yeast and/or bacterial cultures and have been used to improve fiber digestion and enhance intake performance, particularly in times of stress. They may provide a cost effective benefit in some circumstances.

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Mold and mycotoxin inhibitors

Mold and mycotoxin inhibitors can be divided into three categories: (1) mold inhibitors such as propionic acid, which are used to prevent mold growth, (2) adsorbents, such as bentonite or activated clays, which are designed to bind with mold toxins to prevent mold absorption, and (3) direct fed microbials, which can metabolize or detoxify some mycotoxins. All may be of some benefit in circumstances where feeding mycotoxin contaminated feed cannot be avoided. Need, cost, and response should be assessed and monitored.

Larvacides

Larvacides may be added to dairy cow rations for fly control. The larvacides pass through unabsorbed and are present in the manure to kill developing larvae. They are not a substitute for good hygiene.

ANALYSIS AND EVALUATION OF FEED CONSTITUENTS

Regardless of the feed being used to formulate a dairy cow ration, the first step is to obtain accurate measurements of the nutrient content. For some feeds (most grains, soybean meal, minerals, vitamins, additives), "book values" from publications are usually adequate measures of their nutrient content. There are many sources of feed information (Dale, 1998; NRC, 2001; Linn et al, 1989; MacGregor, 1989; Penn State Extension Service, 1995). For all forages, most by-product feeds, and some grains, laboratory analyses are necessary to determine nutrient content. The sample being analyzed must be collected carefully so that it is a good representation of the feed that is to be fed. Box 11-2 shows some of the more common constituents of feeds that are routinely determined by laboratory analysis.

Fig. 11-4 is a schematic representation of the constituents of plant materials in dairy feeds, broken down in three different ways (Linn et al, 1989). The center column depicts the main chemical constituents of a feed. The left-hand column depicts the results of the proximate analysis (Weende) system. In this system, ash is determined by burning part of the sample to destroy all organic components. Ether extraction of another part of the sample removes all lipids (fats). Total nitrogen is measured and crude protein is calculated by multiplying nitrogen by 6.25 (on average, protein is 1/6.25, or 16% nitrogen). Crude fiber is calculated by the residue remaining after successive boiling of a sample with dilute acid and alkaline solutions. A nitrogen-free extract can then be calculated by subtracting the other components that were measured. Proximate analysis is the system legally required for feed labeling but is an anachronism that is little used by nutritionists in formulating dairy cattle diets.

In the Van Soest system, ash, lipid content, and crude protein are determined as in a proximate analysis. NDF is determined by subjecting a sample to treatment by a neutral detergent solution and measuring the residue. Treatment with sulfite and α-amylase may then be applied to leave true NDF complex without any complex starch. It is the least destructive of the fiber measurements. NDF includes lignin, cellulose, and hemicellulose. Acid detergent treatment is more destructive, leaving only some of the lignin and cellulose. ADF is frequently used to predict the energy content of the feedstuff. The protein in a feed sample can be corrected for unavailable protein by subtracting out the ADF-bound protein content predicted based on the nitrogen content in the ADF. Predictions of DMI are better based on NDF content, particularly if corrected for physical form (Linn et al, 1989).

BOX 11-2

Nutrient Constituents of Feeds Commonly Reported by Analytic Laboratories

Dry matter
Energy and fiber
Acid detergent fiber
Neutral detergent fiber
Net energy of lactation (calculated)
Nonfiber carbohydrate (calculated)
Ether extract or fat
Starch
Protein
Crude protein
Heat damaged or unavailable protein
Undegraded or bypass protein (calculated)
Soluble protein
Macrominerals
Calcium
Phosphorus
Magnesium
Potassium
Sulfur
Trace minerals
Copper
Iodine
Iron
Manganese
Zinc
Other
Ash
Lignin

The proximate analysis and Van Soest systems for feed analysis are both wet chemistry approaches. Another, more rapid approach for determining nutrient content is the use of near-infrared radiation (NIR) testing of feeds. Based on the spectrum of absorption of infrared light on a feed sample, nutrient content can be predicted. The accuracy of NIR testing is dependent on the number of calibrating samples of a particular feed that have been used to provide the data for predicting equations. The NIR test can be accurate for commonly tested feeds with reasonably normal nutrient content and has the advantage of being cheaper, quicker, and portable. Whatever the analytic method used, it is essential that the laboratory used for analysis be accurate, consistent, and reliable.

FEEDING SYSTEMS FOR DAIRY HERDS

There are several major systems for feeding dairy cattle, each with its own advantages and disadvantages. With excellent management, any system can be effective. The challenge is to find systems that are effective and efficient for the management level on the farm.

Pasture

Pasture-based feeding systems can generate excellent profit per cow, and in many cases are much less capital intensive than other systems. For that reason they are increasing in popularity in North America. They have long held a dominant position in Australia and New Zealand as well as

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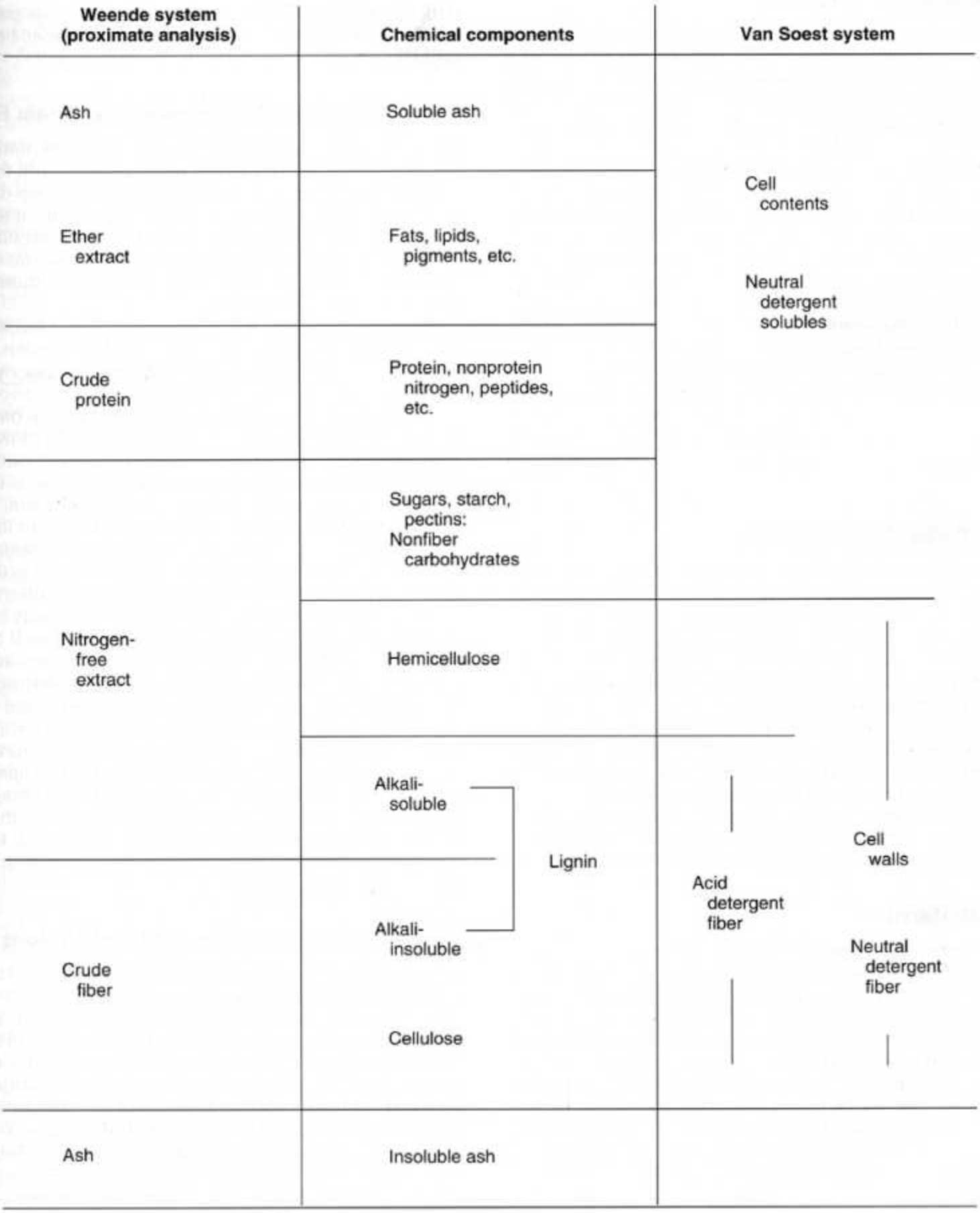

FIG. 11-4 Nutrient and structural components of feedstuffs. (From Linn JG, Hutjens MF, Howard WT, et al: *Feeding the dairy herd,* North Central Regional Extension Pub No 346, St Paul, 1989, University of Minnesota, Minnesota Extension Service.)

lesser developed countries. In Europe, utilization of pasture is somewhere in between that of New Zealand and North America. For maximum benefit, pasture should be managed intensively with frequent movement of cows between paddocks and limited time spent on a given paddock. In North America, maximum profit with pasture systems usually occurs by seasonally calving the cows, so pasture utilization is best matched to cow requirements, and by providing significant concentrate supplementation (Schraufnagel et al, 1998) Provision of water and shade and laneway maintenance are major issues affecting pasture utilization and profitability. Pasture systems usually require less labor and less manure management and produce less milk per cow.

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Stanchions and Tie-Stall Barns

In these systems, cows spend much or all of their time constrained in individual stalls. Cows may be fed their entire ration in the stanchions or may consume a variable amount of the feed (particularly forages) free choice from separate feed bunks during exercise or turn-out periods. Stanchion systems usually require more labor per cow than free-stall systems. Mechanized feeding and TMRs are more difficult to implement in stanchion barn systems but can be done effectively. Labor-saving mechanization in stanchion barns is commonly more expensive than with other systems. Stanchions offer the advantage of allowing individual cow care and feeding. Stanchion barns are typically warmer and more comfortable for the dairy producer in climates with cold winters, although these same "warm" barn systems also tend to provide inadequate ventilation for the cow's comfort and health. Where forages are fed free choice outside the stanchions and mostly grain is fed in the stanchion, there is a risk of rumen acidosis. Because cows can eat variable amounts of forage from the bunks, they might not achieve the proper balance of forages and grain.

Milking Parlor Grain Feeding

A once-popular approach to feeding grain to dairy cows was to provide grain feeders in the milking parlor. These individual feeders were metered so that each cow could be fed her individual grain ration to match her production. Parlor grain feeding suffers from several problems. First, high-producing cows may simply not have enough time to eat their allotted grain during milking. Second, the timing of grain feeding may not match forage intakes, leading to a twice-daily risk of rumen acidosis. Third, the metering systems in milking parlors are commonly out of adjustment or dysfunctional, leading to errors in the amounts fed. Eliminating parlor feeding speeds cow flow through the parlor and reduces dust and defecation during milking. Today, very few operations feed concentrate in the milking parlor.

Free-Stall Barns

Free-stall housing is typically cheaper to construct and requires less labor than stanchions or tie stalls. Cows are fed in bunks, with a variety of systems for feeding grains. Unless they are properly designed and maintained, free stalls may become uncomfortable for the cow and for the operator. As is true for all types of high-density housing, if good ventilation is not provided for in the building's design, air quality, cow comfort, and health may suffer. If humid air is allowed to collect and condense under the roof, structural damage to the barn may also develop. The following describes typical feeding systems found in free-stall operations.

Bunk Forages with Top-Dressed Grain

The simplest system for feeding cattle in free stalls is to provide the forages in bunks, with the grain or concentrate portion (including trace minerals and vitamins) placed on top of the forage. Hay might be fed separately in racks. On many farms feeding with this system, cows are commonly grouped by production so that low-producing cows can be fed less concentrate top dressed on their forages. This feeding system is easy to organize and requires little or no special mechanical system. It has the disadvantage that dominant cows may consume more grain than less aggressive ones. Grain may be consumed in large quantities first, without adequate forage intake to encourage cud chewing and provide for buffering. The dominant cow risks nutrient imbalance and rumen acidosis, whereas the more timid cow eats less grain and is shorted for nutrients. Her milk production or health may suffer.

Bunk Forages and Individual Cow Grain Feeding

There are several systems for feeding the grain portion of the ration to cows housed in free stalls. Commonly, forages are fed in bunks. Part of the grain might be fed top-dressed on the forage, with additional grain fed in relation to production in the milking parlor. Again, such a system suffers from the disadvantages of both parlor feeding systems and from top-dressed bunk grain feeding. This system must be managed carefully to be effective.

Another method of individual grain feeding is by transponder, magnetic key, or computer feeders. Each of these systems attempts to allow access to extra concentrate for high-producing cows while denying access to others in a free stall. Each cow wears a mechanical device on her neck chain that is recognized by a specialized stall. As the cow enters the stall, the system releases a measured amount of grain to the cow. The simplest system feeds all cows with a "key" (e.g., chain, magnet) the same amount of grain. Sophisticated computerized systems use transponders to identify individual cows. The system can feed specific amounts to different cows and simultaneously feed different grains to the same cow (to balance energy and protein at different levels). These computer systems can track the amounts consumed by individual cows and flag the dairy producer if cows consume less grain than expected. The computerized systems can dole out small portions many times during the day, smoothing the rate of grain consumption and reducing rumen input variation. These computerized systems must be managed carefully to ensure that complex systems of feeding equipment, hardware, software, and ration design all work together. The stall layout and number of stalls must be adequate to allow timid cows to have access to the system. Heifers often must be trained to use the system. Computer systems require significant initial capital investment and may not be cost justified.

Blended Rations and Total Mixed Rations

In TMRs, the forages and concentrate portions of the ration are first mixed together and then delivered to the bunk to be eaten. They can be fed both in free-stall and in stanchion barn systems. To work well the various portions of the ration must be weighed to ensure that the mix matches the ration design. There are a variety of mixing systems, including both stationary mixers (that deliver feed by motorized belts, feeder wagons, or feed carts) and mobile mixers mounted on wheels that can deliver feed directly to the bunk. Some TMRs include all portions of the ration, including the hay, whereas others blend the silages, concentrates, and by-product feeds for the bunk while feeding hay separately. TMRs have distinct advantages over other feed delivery systems. They lend themselves to total mechanization and make it easier to incorporate by-product feeds into the ration. Total DMI and milk production are commonly increased compared with the same feeds fed using other systems (McCullough, 1991). TMRs may make hay feeding difficult and require frequent adjustment if the dry matter content of silages changes.

The relative constancy of ration and rumination in diets fed as a TMR may account for some of their advantage over other approaches to feeding dairy cows. With a TMR, each mouthful eaten is much the same as the next, so the rumen environment is more stable. The mechanized systems needed to manage a TMR require initial capital outlay. As in

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all dairy rations, forage nutrient content should be based on laboratory analysis, not feed table averages. In most areas of the United States, a TMR is the most common way to feed dairy cattle.

TMRs may have their greatest influence if the farm can separate cattle into different feeding groups. There are several strategies for grouping. Some dairies group based on production levels to try to save money in the formulation of rations to lower-producing cows (Linn et al, 1989). On other farms, particularly high-producing herds, grouping strategies might be based more on stage of lactation or reproductive status (early postpartum versus later, not pregnant versus pregnant) or parity (heifers versus older cows) (Sniffen, 1991). In every case, dry cows should be fed separately from lactating cows.

BALANCING RATIONS

Ration analysis can be a highly effective aid for the diagnosis of deficiencies in a feeding program. Once such deficiencies have been identified, however, the next logical question is "What should be fed?" For this, ration balancing programs are needed. Historically, the ability to formulate rations for dairy cattle has been limited by two constraints: (1) knowledge of ruminant nutrition, including both animal requirements and the physiology of fermentation, digestion, and absorption, and (2) computational ability to incorporate knowledge into a mathematical system for calculating rations.

Simple algebraic calculations have been used to balance rations for basic requirements such as crude protein, calcium, and phosphorus concentrations. An algorithm known as a "Pearson square" was a method frequently used to determine the proportions of two feedstuffs in a mix with a desired final concentration. Programmable calculators permitted easier diet formulation because of their ability to do a large number of algebraic calculations quickly and were widely used in dairy cattle diet formulation and evaluation before the availability of computers. The formulator could compare the diet being evaluated with requirements, either in desired concentrations or amounts. If more or less of a specific nutrient was needed, the amount of various feedstuffs could be altered and the nutrients supplied in the new diet compared with the requirements. This "cut and fit" approach is also the basis for many ration balancing programs available today, which are sophisticated spreadsheets that permit rapid comparison of provided nutrients with required nutrients. They provide a skilled consultant with an effective, rapid method of formulating rations.

Linear programming is a ration balancing method requiring greater computer computational capacity and more complex mathematics. Linear programming (LP) nutrition software is the application of a more general mathematical technique that involves the optimum solution of a constrained problem. The mathematical approach is applied widely in business in fields as diverse as oil refining, ambulance allocation, personnel scheduling, and stock investing. In nutrition, the technique is applied to optimize an outcome (develop a least-cost ration) subject to certain constraints (nutrient requirements, feed limits, DMI limits). The linear programming process calculates the cheapest possible ration that can satisfy the constraints specified (VandeHaar and Black, 1991).

The desired end in a linear program is a linear equation called the objective function. In dairy ration programming the objective function is an equation calculating the total cost of the ration (the amount fed times the price for each feed, summed for all feeds in the ration). The program is designed to minimize this equation. For a dairy LP there are also sets of linear equations called constraints. In general, there are two types of constraints: nutrient constraints and feed constraints.

Fig. 11-5 illustrates a simplified example of a linear program to solve for a least-cost balanced ration. In the example, only net energy, crude protein, and bypass protein are considered. The bottom two sections show the solution calculated by the LP program. The "Objective" section shows the costs of each feed in the final solution and the sum, $3.62, for the ration as a whole. This is the cheapest ration that satisfies all the example's constraints. The bottom section shows that this ration contains 6.5 kg of shelled corn, 3.9 kg of soybean meal, 4 kg of distiller's grains, 30 kg of corn silage, and no hay. What was the setup that created this solution?

The top section sets the nutrient requirements that must be met by the final solution. The Feed Specifications section describes the cost and nutrient contents of the feeds that can be used. The next section sets the nutrient constraints. For example, consider DMI. The nutrient requirement (LP limit) is set at 22 kg of dry matter. The amount of dry matter contributed by each feed in the solution is calculated and then summed on the dry matter line in the "Nutrient Constraints" section. The amount fed times the dry matter percentage, summed for each feed (a linear equation), is the total dry matter in the ration. This total is constrained to be less than a certain value (e.g., 22 kg for a high-producing cow). In the optimum solution in the example, the sum from all feeds exactly meets the constraint of 22 kg of dry matter. The program found that the cheapest solution was to feed as much dry matter as possible.

Feed constraints are limits set on the amounts of each feed that can be fed. For example, farm inventories might restrict the ration to use no more than 20 kg of corn silage/cow/day. Feed constraints are also linear equations, albeit trivial ones. For shelled corn, for example, the equation is as follows: (1 × amount of corn) + (0 × amount of soybean meal) + (0 × amount of distiller's grains) + (etc.) = amount of corn fed. As the example shows, each feed fell within its constraining LP limit. The solution fed all the distiller's grains and corn silage it was allowed, and could have fed more shelled corn, soybean meal, and grass hay if it would have made a cheaper mix.

Nutrient and feed constraints can be set as minimums or maximums. For DMI, the constraint level is the maximum amount of dry matter the cow can consume. For crude protein, the 3.7-kg setting in the example is the minimum amount of protein that can be allowed. Constraints can also be set as equals. For example, selenium might be set so that it must be fed at exactly 0.3 ppm in the diet. Setting "equal to" constraints for macronutrients generally complicates the chance of finding a solution. Often, constraints are set as windows by having two constraints for the same item. For example, a window for shelled corn might be set that specified that a minimum of 2 kg, but no more than 8 kg, must be fed. This would force at least some shelled corn into the ration.

In practical use, then, an LP program requires the same inputs as a cut-and-fit program (feed library, nutrient requirements) but also requires prices and constraint settings. Once these are set, the program attempts to find a feasible solution that minimizes costs while satisfying the constraints. If the constraints are set so that no feasible solution can be found, the program returns an infeasible solution message. For example, suppose that, by mistake, the program limits for DMI were set at 2.2 kg instead of 22 kg. There is no way to satisfy the cow's nutrient needs in a 2.2-kg package, so the program would return an infeasible solution message. Different packages provide differing amounts of information about why an infeasible solution was reached.

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Nutrient requirements and limits

22 kg expected total dry matter intake

37.0 Mcal NE(l)	(1.68 Mcal/kg of dry matter intake)
3.7 kg crude protein	(17% crude protein in dry matter)
1.3 kg by-pass protein	(6% by-pass protein in dry matter)

Feed specifications

	Shelled corn	Soybean meal	Distiller's grains	Corn silage	Grass hay
$/1000 kg	$150	$280	$200	$25	$120
Dry matter	90	90	90	30	90
NE (L)	1.76	1.72	1.72	1.60	1.32
Crude protein	8.0	44.0	28.0	8.0	16.0
By-pass protein	4.0	16.0	16.0	2.0	4.0

Nutrient constraints

	Shelled corn	Soybean meal	Distiller's grains	Corn silage	Grass hay	Total fed	LP limits	Slack	Shadow price
Dry matter	5.9	3.5	3.6	9.0	0.0	22.0	22.0	0.0	($0.13)
NE (L)	10.4	6.0	6.2	14.4	0.0	37.0	37.0	0.0	$0.15
Crude protein	0.47	1.54	1.01	0.72	0.00	3.7	3.7	0.0	$0.42
By-pass protein	0.24	0.56	0.58	0.18	0.00	1.6	1.3	0.2	$0.00

Feedstuff constraints

	Shelled corn	Soybean meal	Distiller's grains	Corn silage	Grass hay	Total fed	LP limits	Slack	Shadow price
Shelled corn	6.5					6.5	8	1.5	$0.00
Soybean meal		3.9				3.9	5	1.1	$0.00
Distiller's grains			4.0			4.0	4	0.0	($0.02)
Corn silage				30.0		30.0	30	0.0	($0.02)
Grass hay					0.0	0.0	5	5.0	$0.00

Objective: minimize total feed costs

Total cost	Cost of each feed ingredient in the ration				
$3.62	$0.98	$1.09	$0.80	$0.75	$0.00

Solution: amount to be fed for a least cost ration

	Shelled corn	Soybean meal	Distiller's grains	Corn silage	Grass hay
amount (kg)	6.5	3.9	4.0	30.0	0.0

FIG. 11-5 Simplified example of linear programming.

Better packages at least say which constraint appears to be the problem. In general, working toward a feasible solution involves "loosening" some constraint and rerunning the LP. Many LP packages have the disadvantage over cut-and-fit packages in that they are rather like black boxes. Inputs, requirements, and constraints are entered and an answer is derived, but some of the underlying relationships are not at all clear. Like any mixture of art and science, using an LP effectively takes time, mentoring, and experience.

LP programs have a distinct advantage over cut-and-fit approaches because they provide a least-cost solution for a particular ration. They do not guarantee, however, that the ration developed by the LP program is biologically sound. Once a feasible solution is found by the LP software, it often cannot be fed to a dairy herd. Often the best mathematically feasible solution is not biologically feasible. The example's optimum ration, for example, fed 30 kg of corn silage without "knowing" that cows are probably not able to eat that

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much wet forage. The practitioner would have to go back and reduce the LP limit for corn silage and rerun the LP. Finding a good solution is also an iterative process, therefore, just like the cut-and-fit process. No program can completely replace the need for the knowledge and experience of the person running it.

Whether a "cut and fit" spreadsheet or least cost linear program is used to balance a ration and formulate a diet, the requirements programmed into the system will be based on a model. In general, this model will be either an empirical or mechanistic model, or a combination of the two. Empirical models are developed strictly from experimental observation; they mathematically express relationships that have been observed. They can be highly accurate and precise, but they may or may not be based on the biology of the system or our understanding of that biology. A mechanistic model uses an understanding of the biology of the system to arrive at an estimate of the requirements. An empirical model may be very accurate at predicting results or requirements on observations or circumstances similar to those that were used in the data set that was used to develop the model. Observations under different circumstances, however, are probably not predicted accurately. A mechanistic model, on the other hand, is developed in an attempt to use an understanding of the biology of the system to predict results. It may or may not be more accurate than an empirical model predicting the same thing(s), but the mechanistic model is probably more useful in predicting relationships or outcomes in circumstances significantly different than those used in developing the model. In dairy nutrition a good example of use of an empirical model is that used to predict NE content of a feed by measuring ADF. The more mechanistic model using NDF, fat, lignin, crude protein, and ash content to estimate the energy content of the feed may not be more accurate on typical forages but probably is more reliable when incorporating byproduct feeds or atypical forages into the diet (Weiss, 1993).

Computer programs used in formulating rations for dairy cattle today involve both empirical and mechanistic components. As more sophisticated mechanistic models are developed, understanding of the biology of the system should improve by testing and observing against predictions.

Regardless of the model embedded in the program used to balance a ration, and irrespective of whether a "cut and fit" or linear programming method is used, the priority and constraints of nutrients needed should be similar. The first constraint will be DMI. The nutrients needed must be delivered within the dry matter that the animal actually consumes. At several times during the lactation cycle, it is difficult, if not impossible, for a dairy cow to eat enough of a diet that will meet all of her energy needs. Prediction of DMI remains largely empirical, and direct measurement when formulating diets is much preferred over use of computer predictions. After DMI constraints are observed, the nutrient that should receive first priority when formulating dairy cattle diets is the fibrous fraction. Providing adequate fermentable fiber and avoiding excessive rapidly degraded carbohydrate are critical to maintaining a healthy rumen ecosystem and avoiding rumen acidosis and its associated complications. A conflict arises when formulating early lactation diets because attempts to increase the energy density of a diet tend to result in a reduction in fermentable fiber. The best measure of adequate fiber is subject to debate and was discussed in more detail earlier in this chapter. Whatever method is used to determine fiber adequacy—NDF, forage NDF, peNDF, forage particle size, or forage:concentrate ratio—this requirement should be met first.

The next priority should be providing adequate degradable energy and protein to meet the requirements of the rumen. This includes sufficient fermentable carbohydrate for productive rumen fermentation. Research suggests an optimum concentration of fermentable carbohydrate is needed. Less than or more than the optimum compromises rumen function and energetics. Too high a concentration of NSC, NFC, starches, or sugars results in rumen acidosis. Too low a concentration provides inadequate substrate for microbial growth. In vitro observations and clinical trials suggest this optimum to be 35% to 40% NSC. Degradable protein—including ammonia and peptide sources—should be adequate to support the microbial fermentation of available carbohydrate. Between 9% and 13% of ration DM (60% to 65% of CP) is an optimum concentration of degradable protein. A ratio of NSC:degradable CP of 3.0 to 3.3 may optimize rumen microbial output (Hoover et al, 1990). Once dietary ingredients and amounts supporting productive rumen fermentation have been incorporated into the diet, additional concentrated energy sources such as supplemental fat and additional undegraded protein or amino acids should be incorporated into the diet at levels appropriate for the desired production response. The first priority should be to support a healthy rumen fermentation by addressing fiber, degradable carbohydrate, and degradable protein requirements! Supplemental vitamins, macrominerals, and trace minerals then should also be incorporated into the diet in appropriate amounts.

Whether using an empirical or mechanistic model, a "cut and fit" or linear program, this sequence of steps for ration balancing is appropriate to use in formulating dairy cattle diets and gives first priority to supporting top rumen function.

Designing the Diet as a Whole

The cow's diet must be seen as a whole, not as a series of parts. The calculated balance of a ration may be accurate when summed over a whole day but significantly unbalanced when fed piece by piece to the cow. The nutritive value of the parts depends on how they are consumed by the cow in relation to other parts of the ration. When TMRs are fed, this is of less concern; each mouthful is generally the same, and the homeostasis of the rumen is optimized. However, attention to rumen release rates of carbohydrate and protein, for example, are important. Feeding lots of rapidly degradable protein without rapidly available carbohydrate could produce a wasting of both protein and carbohydrate in a TMR, even though total amounts of protein and carbohydrate were fed in "correct" amounts. When different constituents are fed separately, the order and timing of the feeding program become more important. For example, if grains are fed in the morning before the cow has eaten enough forage to stimulate buffering, then rumen acidosis may result. If rumen-degradable protein is not fed in time to match the needs of the microbes as they digest the carbohydrate fractions, then fiber digestion may be impaired and microbial protein production reduced. There is art and skill to the process of delivering rations to cows if production is to be optimized. Efforts to encourage consistency in content and frequency of delivery are generally well rewarded.

MONITORING DAIRY FEEDING PROGRAMS

If a veterinarian is providing nutritional consulting services, then a routine, consistent monitoring service is essential. There are many parameters that can help determine the adequacy of a feeding program. A well-conducted production program incorporates these into its routine monitoring services on the dairy.

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Dry Matter Intake

DMI should be measured routinely and is best done daily. Actual measurements are a must. Some method needs to be arranged for measuring the total feed fed and feed not consumed, so that an accurate picture of intakes is available. To accurately measure DMI, a convenient method of measuring dry matter is essential. Electronic measuring devices are simple and convenient, though can be relatively expensive. Their accuracy requires fairly careful maintenance, too. The use of a microwave oven to dry the forage and weigh the residue is accurate and effective, but tedious. Use of an inexpensive food dehydrator has proved to be a convenient method of drying a sample to determine its dry matter content. A comparison of methods has suggested all are generally accurate (Oetzel et al, 1993). If DMI varies significantly from predicted values, adjustments in the ration or investigation of the reasons for the variance are indicated.

Feed Quality

Monitoring feed quality means many things. First, look at the feed itself. Is it fresh, clean smelling, free of foreign material, homogeneous, and free of evidence of mold? Run laboratory analyses for nutrient content and, where appropriate, for toxins, particularly mycotoxins.

Fecal Consistency

Fecal consistency and content, easily monitored at each herd visit, can provide valuable information about the cow's digestive status. Overly firm feces suggest too much fiber or too little water. Overly fluid feces may reflect too little fiber (too much readily fermented carbohydrates), too much fat, or too rapid a passage rate. Whole grain in the manure suggests inadequate rumen fiber mat formation to trap grain until it can be fermented. It may also be observed with excessively dry corn silage, where the starch is less digestible in the rumen. "Greasy" manure may indicate too much rumen-degradable protein.

Cud Chewing

If undisturbed, most cows should be either eating at the bunk or lying down and chewing their cud. If many cows are seen standing while chewing their cud, it is a clear indication that the free stalls or stanchions are uncomfortable. At any given time, 60% to 70% of all cows lying down should be chewing their cud. If not, total effective fiber intake may be inadequate. If cows show an unusual habit of chewing on walls or fences or eating dirt, consider too little fiber as a possible cause as well as pica from inadequate phosphorus intake.

Body Condition Scoring

The body condition of dairy cattle can be scored easily and consistently on a 1 to 5 scale (Wildman et al, 1982). The system is fairly simple to learn and there are excellent charts to guide the scoring process (Edmonson et al, 1989). The score correlates well with total fat stores in the cow. With training, this measure is repeatable across time and across observers (Edmonson et al, 1989).

Body scoring is based on the degree of flesh covering the skeleton of the lumbar vertebrae (loin), the pelvis (hooks, pins, and the area between them), and the sacral and coccygeal vertebrae (tail head). Palpation may be helpful, but visual inspection alone is sufficiently accurate. Scoring can usually be performed to a quarter-point level. Most lactating dairy cows fall between body scores of 2 and 4. Box 11-3 summarizes the criteria for condition scoring.

Changes in body score provide an indication of weight loss and weight gain during lactation. Under normal conditions, cows lose weight in early lactation as milk production exceeds their ability to consume enough dry matter to supply their nutrient needs. Excessive losses of body condition in early lactation are associated with reduced reproductive performance (Butler and Smith, 1989). Cows that lose more than one body score point have significantly reduced first-service conception rates and have increased days to first ovulation and first observed estrus. Cows should calve with body scores of 3 to 4 and should lose no more than one point during early lactation. Ideally, the loss should not exceed half of a body score point. Weight is most efficiently gained during the end of lactation, rather than during the dry period, so mid- and late-lactation rations should allow for extra energy to support increasing body condition (Moe et al, 1971). Body condition gains during the dry period may lead to "fat cow syndrome" and peripartum disease (Morrow, 1976). The ideal body condition may vary according to herd. Herds that manage DMI well may prefer a slightly greater body condition score (BCS) than those that do not. One study suggested cows calving at 3.0 to 3.5 were more profitable than those at 3.5 to 4.0, as there were no differences in production and performance between groups, but heavier cows had a longer period of BCS loss and gain than thinner cows (Ruegg and Milton, 1995). In all herds the average BCS is not nearly as important as the number of outliers—the number of cows that are too fat or too thin at a given lactation stage.

Milk Production

Many different parameters monitor milk production. Most are derived from DHIA reports, although more and more dairy producers are using on-farm testing equipment that can provide daily and summary milk production data. No single parameter is adequate for monitoring milk production on a dairy. When using a parameter to monitor milk production over time, one must keep the momentum of the parameter in mind. The momentum of a parameter is the rate at which the parameter can change as the actual farm situation changes. Parameters that include a great deal of history in their calculation have high momentum—that is, they cannot quickly reflect a sudden change in the herd's status. The rolling herd average, for example, carries a full year's history in its calculation. Short-term production fluctuations do little to change the rolling herd average. High-momentum parameters have the advantage of providing a better measure of the general trend, but they can obscure sudden changes for the worse that deserve immediate attention. Low momentum parameters such as daily milk per cow can change quickly in response to changes on a farm. They are sensitive measures of change, but the use of them as the sole monitoring index can lead to erratic and reactive management. Frequent changes of management in response to low-momentum parameter shifts can actually lead to wider swings in performance as consistency is lost to inappropriate responses to each next "crisis."

Whatever the parameter, remember that monitoring is about trends more than about absolutes. Keep track of the same parameters month to month and watch changes over time. For many parameters, it is also often useful to partition the herd into categories by lactation number and stage of lactation for monitoring purposes. For example, milk production may be fine in older cows, but a change in bunk space or cow numbers may create havoc with first-lactation animals in early lactation.

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BOX 11-3

Body Scoring

SCORE 1: SEVERE EMACIATION

Individual bony parts are all prominent: the vertebrae are sharp and distinct, hooks and pins are sharp, with negligible flesh covering them, and the pararectal fossa below the tail head is deeply sunken. The area over the gluteal musculature (between hooks and pins) is severely sunken. This score is extremely rare in healthy dairy cattle. It is indicative of severe cachexia.

SCORE 2: THIN CONDITION

Bony processes are notable, but not sharp. Individual lumbar vertebrae are not distinct but are visible. The transverse processes of the lumbar are prominent and stand out sharply. They form a notable shelf. The area between the hooks and pins is more filled than with a score of 1 but is still concave. The pararectal area is still concave and depressed, but the bones have a fleshy covering.

SCORE 3: MODERATE CONDITION

There is a smooth covering of flesh over all bony parts. Individual lumbar prominences are not visually discernible but form a rounded ridge. The transverse processes of the vertebrae no longer form a distinct shelf. Pins and hooks are rounded. There is only a slight concavity between them. The pararectal fossa is smooth, without obvious fat filling.

SCORE 4: HEAVY CONDITION

All bony parts are well covered. The lumbar area is fat, with no dorsal processes of the spine visible. The hooks and pins are well covered and the area between them is flat. The tail head is surrounded by obvious subcutaneous fat.

SCORE 5: OBESE

Almost no bony structure is visible. There is significant subcutaneous fat. A body score of 5 is rare in dairy cattle.

Milk per Cow per Day

Perhaps the most easily collected number, milk per cow per day, can be calculated by dividing the amount of milk shipped by the number of cows milking and the days since the last milk pickup. It should be adjusted for cows whose milk was not added to the bulk tank (e.g., treated cows, fresh cows, or mastitic cows). Milk per cow per day can vary widely day to day in response to feeding changes, cows dried off or newly freshened, weather, and milking crew. It is probably too sensitive (too low momentum) to be relied on heavily, particularly in small herds. Like DMI, it should be monitored frequently, but one should avoid overreacting to small variations.

Rolling Herd Average

This is a calculated estimate of the amount of milk produced by the average cow in the herd during the past year. If milk per cow per day has the least momentum of milk production indices, the rolling herd average has the most. Major changes in overall herd productivity can occur, and the rolling herd average will be largely unaffected for several months. The rolling herd average is, however, the measure most often watched by most farmers, because it correlates well with annual income for milk sales. The quality of a dairy is usually summarized by citing the herd's rolling herd average. The rolling herd average does not necessarily correlate well with a herd's profitability, because two herds with the same level of production (revenue) may have different levels of debt and operating and feed costs (expenses).

Even given the inadequacy of the rolling herd average in characterizing a herd's current biologic or financial status, it still is useful to understand the forces that drive it. Rolling herd average is affected by the following three major factors:

"Real Productivity"

How well is each cow in the herd milking in terms of her genetic potential? Obviously, this is affected by a host of factors, such as nutrition, housing, and health. This real productivity consumes most of the attention of the production medicine clinician.

Herd Demographics

How many first-lactation animals versus older cows are milking? For example, the rolling herd average is likely to drop in the near term in a herd that is actively culling cows for staphylococcal mastitis and replacing them with heifers. Neither the remaining cows nor the heifers are milking less than expected. Heifers simply make less milk than older cows, on average.

Reproductive Efficiency

Herds in which average days open creeps up gradually find that cows are spending more of each lactation at the end (i.e., where production is lower). The cows' milk production is not reduced from normal; rather, the cows are simply spending more time at a less productive stage of lactation. Thus some drops in the rolling herd average reflect inadequacies in the reproductive program, not the nutrition or genetic program or other aspects of management.

Adjusted Corrected Milk, Standardized Milk, Management Level Milk

As a seasonally calving herd moves through the year, there are times when most of the herd is in early lactation (fresh herd) and times when most of the herd is at the end of lactation (stale herd). Milk per cow per day is less in a stale herd than in a fresh herd, even with the same cows at the same level of real productivity. Because of the desire to compare production among different months without confounding the herd's seasonal status, several different calculated measures of production have been developed. Each attempts to adjust for the herd's average days in milk, and some adjust for the herd's demographics and herd butterfat production (Nordlund, 1987). In general, these measures are superior to monthly milk per cow per day in monitoring for real changes in productivity.

Lactation Curves

Lactation curves of milk production are typically summarized by two parameters, peak (or summit) milk and persistency. Peak production is the point of maximum daily milk output, usually within the first 2 months of lactation. The

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magnitude of peak determines much of the shape of the total lactation curve. For every kilogram of additional peak milk production, the cow gives approximately 200 kg of milk more in the first 10 months of lactation. Persistency refers to the rate of decline in production beyond peak. Good persistency means a relatively low rate of decline. Mature cows typically decline between 8% and 10% of peak/month. Heifers have lower peak productions than cows, but the persistency of their lactation is generally better than for cows. Declines in heifers are usually between 4% and 6% per month. Use of recombinant bovine somatotropin has significantly changed the persistency component of the lactation curve; a slower decline is observed in herds using this product.

Much has been made of graphic lactation curves for cows. Milk by stage of lactation, as well as butterfat, protein, and SCCs, can all be graphed. Generally, one of two types of herd or group curves are generated. In the first, the data from one day's herd DHIA test are used to plot production by days in milk. In a sense, this is like milk per cow per day that it is low momentum, and it reflects only the herd's current status. This sort of graph may be useful for identifying cows that are "outliers" in terms of expected production. This type of graph suffers from the fact that the cows graphed in early lactation are different from those graphed in later lactation. It is easy to be tricked into thinking that those early-lactation cows will follow the pattern set by those in late lactation. This may not be the case. For example, cows in early lactation in July in the southeastern United States follow different lactation curves than their herd mates, who calved in the previous winter.

In the second type of lactation curve, all test day data for each cow's current lactation are used to construct the graph. This is similar to the rolling herd average and has a high amount of momentum. It risks masking serious, current, early-lactation problems by mixing recent performance with performance from as long as 10 months ago.

Both types of lactation curves can suffer from the danger of using averages alone to describe a population's status. They can mask a great deal of variability and trouble in individual cows as they aggregate the data into a smooth curve of average points by stage of lactation. Curves based on few individuals can be skewed widely by a single outlier cow. Viewed as a diagnostic test, lactation curves run a risk of both false-positive and false-negative diagnoses for significant herd problems and must be interpreted with caution (Galligan and Ferguson, 1991).

305 Mature Equivalent and Breed Class Average

The calculations for 305 mature equivalent (ME) and breed class average (BCA), provided by the DHIA and some microcomputer records programs, provide an "apples to apples" method of comparing two cows of different age and stage of lactation, or for comparing the same cow over time. The calculation process involves first projecting the cow's actual milk production in her first 305 days of current lactation. For this reason, 305 MEs cannot be calculated for cows until they have more than one DHIA test and are far enough into their lactation so that an accurate prediction can be made. Once the actual 305-day projection is made, it is multiplied by a factor that adjusts for the cow's age at calving and her season at calving. The adjustment factors are specific for each region and reflect the region's average effects of season, age, and genetics. In Canada, BCA calculations then take these adjusted numbers and standardize them to a hypothetic standard cow with a score of 100. Thus a cow with a BCA of 140 is 40% more productive on a mature equivalent basis than the standard cow.

Although no single measure is a sufficient monitor of productivity, of all DHIA milk production parameters, 305 ME milk production (or BCA) is probably the best single monitoring parameter for real productivity and therefore for the effectiveness of a nutrition program. Mature equivalent production takes out the effect of the herd's reproductive status by considering only the first 305 days of lactation. Thus a cow with prolonged days open is not penalized in the measure of her lactation productivity. By adjusting all 305-day projections to a mature equivalent basis, heifers are not penalized for being naturally less productive than older cows. The herd's average 305 ME, perhaps broken down by lactation number, is therefore an excellent measure of the real productivity of the herd. It has a moderate amount of momentum and is a useful parameter if trends are followed month to month. Changes in 305 ME milk can also be compared using paired t-tests or sign tests to determine whether an observed change is real or just normal variation (Galligan and Ferguson, 1991).

Milk Components

Milk fat and protein content should be monitored on a regular basis. Deviation in butterfat content of milk is most commonly related to dietary fiber. With inadequate fiber (either form or amount), butterfat level in the milk will be reduced. Milk protein will be influenced by ration energy and carbohydrate content, as well as dietary fat levels. Milk urea nitrogen (MUN) is a relatively recent tool being used to assess the balance between rumen-available protein and carbohydrate in the diet. Target levels for MUN have been suggested to be between 10 and 15 mg per 100 ml. Using MUN levels in association with milk protein can provide more information than either parameter alone (Nelson, 1996).

Disease

Many clinical diseases have their origins in nutrition. Monitoring the incidence of metabolic disease serves as another window on the feeding program. Table 11-8 lists some common nutritionally related diseases and suggests target performance levels for those diseases for monitoring purposes.

Income Over Feed Costs

Although overall profitability is the final goal, farm profit is affected by too many nonfeeding program factors to be an effective monitor of the impact of a feeding program. The most useful practical measure of the economic impact of a feeding program is income over feed costs (IOFC) for milking cows. To calculate this number, the cost of feeding the milking herd is subtracted from the value of milk produced. This remainder is the money left to the dairy producer for all other purposes, such as living expenses, farm labor, interest, and other feeding costs. Calculating the IOFC can be difficult because many farms do not account for feed expenses in a way that allows the costs for the milking herd to be differentiated from total feed expenditures.

Cost of Feedstuffs

Feed costs account for 40% to 60% of all costs on a dairy. There is a major potential to reduce operating expenses by selecting feeds that minimize the money spent on feeds for a given level of production (Galligan and Ferguson, 1991). The most effective approach to monitoring costs of feeds is to collect routine feed prices from normal market channels and to use a linear programming package to set substitution prices for a particular farm.

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TABLE 11-8

Causes, Occurrence, and Prevention of Nutritionally Related Diseases or Suboptimum Performance in Dairy Cows

Signs of Disease or Suboptimum Performance	Cause	Occurrence	Prevention
Simple indigestion, <2% of calvings	Change of feed a few days before or at parturition	Within a few days after calving	Avoid marked changes in nature of feed in periparturient cows
Fat cow syndrome <3% of calvings	Excessive intake of energy during dry period	Within a few days before but most commonly a few days after calving	Feed for maintenance and pregnancy during dry period; feed dry cows separately; monitor body condition score
Parturient hypocalcemia (milk fever) <5% of cows	High calcium and/or potassium intake during dry period; anion-cation imbalance	Within 48 hours before; or after calving; midlactation cases also occur	Feed low-calcium diets during dry period; inject vitamin D metabolites before calving; do not overfeed potassium; feed negative dietary cation-anion difference diet before calving
Hypomagnesia (lactation tetany) rare or none	Relative deficiency of dietary magnesium in lush pasture; stress of cold weather	Within first few weeks after calving	Supplement diet with magnesium at strategic times
Downer cow, <10% of hypocalcemia	Complication of milk fever (traumatic injuries, prolonged recumbency)	Recumbent cases of milk fever fail to rise following treatment with calcium	Recognize and treat cases of milk fever in first stage
Left-sided displacement of abomasum, <5% of calvings	Uncertain; epidemiologically related to feeding grain before calving	Within a few days to a few weeks after calving	Feed adequate transition diet, especially adequate fiber postpartum; feed long hay during dry period
Right-sided displacement and torsion of abomasum, rare	Uncertain; epidemiologically related to high grain feeding in early lactation	Usually 2 to 3 weeks after calving	Ensure high intake of high-quality forage in early lactation
Cecal dilation and torsion, rare	Uncertain; may be related to high grain feeding in early lactation	Usually 2 to 3 weeks after calving	Ensure high intake of high-quality forage in early lactation

Continued

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TABLE 11-8—cont'd

Causes, Occurrence, and Prevention of Nutritionally Related Diseases or Suboptimum Performance in Dairy Cows—cont'd

Signs of Disease or Suboptimum Performance	Cause	Occurrence	Prevention
Primary acetonemia <5% of calvings	Insufficient energy intake because of physical inability to consume, lack of energy in diet, or secondary disease affecting appetite	<6 weeks after calving before peak milk production	Ensure an increasing plane of energy intake in early lactation; ensure adequate transition, especially starch, from prepartum to postpartum ration
Postparturient hemoglobinuria rare	Deficiency of phosphorus intake	2 to 6 weeks after calving	Ensure adequate level of phosphorus in diet
Early-lactation drop in milk production	Insufficient intake of energy and low body condition score at calving, thus providing no body fat for mobilization	6 to 8 weeks after calving	Ensure adequate intake of energy and protein during first 6 to 8 weeks after calving
Postpartum uterine infections <10% of calvings	May be caused by mismanagement of dry cow rations	First month postpartum	Check dry cow ration Ca, Se, vitamin A, watch for over-conditioning during dry period
Lameness, laminitis, ulceration, white line weakness, and abscessation	Inadequate effective fiber	Most common in early lactation; effects long lived	Maintain adequate ration of effective fiber
Milk fat depression	Inadequate fiber	Any stage of lactation	Maintain adequate ration of fiber
Delayed onset of estrus	Inadequate heat detection; may be caused by inadequate energy intake and excessive loss of body weight in early lactation	8 to 10 weeks after calving	Provide good heat detection of cows beginning 40 days after calving; monitor body condition and ensure adequate energy intake
Retained placenta, 5% of non-twin pregnancies	Interference with normal detachment and expulsion of placenta	24 hours after parturition	Provide adequate vitamins A, D, and E in dry period; provide adequate trace minerals especially Se; prevent subclinical hypocalcemia

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FEEDING THE DRY COW

The dry period should best be seen as the beginning of the next lactation. Too often, dry cows and their nutrition are neglected on dairies. Because the nutritional demands of the dry period are far lower than for lactating cows, dry cows are often fed poorly balanced rations of inferior feedstuffs. Many postpartum diseases find their beginnings in the dry period, including hypocalcemia, hypomagnesemia, downers, ketosis, delayed conception, retained placenta, uterine infection, udder edema, and displaced abomasum (Van Saun, 1991). There is a close association among many of these diseases; if a cow suffers from one, she is more likely to suffer from others (Erb and Gröhn, 1988; Erb et al, 1985). More than 60% of the total weight of the conceptus is gained during the last 2 months of the dry period. During the last 1 to 3 weeks of the dry period, the cow must make the transition from body and fetal tissue deposition to tissue mobilization to support lactation (Bell, 1995). This transition means that the dry period really has two phases: the early dry period (or far-out dry period) and the near-parturient phase (or close-up period). The nutrient requirements of the two phases are different, and the best dry cow programs segregate these two groups for feeding and management purposes (Van Saun, 1991).

The far-off dry period (phase 4) requires a diet designed to maintain body weight and allow for fetal growth. This can usually be achieved with relatively small quantities of concentrate and large quantities of forage. Forages fed during this period should *not* include ad libitum feeding of high-energy-density forages such as corn silage or some alfalfa haylages. Ad libitum intakes of these high energy feedstuffs can lead to excessive weight gain and a predisposition to ketosis and hepatic lipidosis. Feeding significant amounts of long stemmed hay or pasture during the dry period is generally considered desirable. It maintains rumen fill. When feeding only ensiled forages in the dry cow diet, there is an increased tendency toward displaced abomasum postpartum (Nocek et al, 1983).

Ideally, the dry period should be between 50 and 70 days long. Shorter dry periods are associated with reduced milk production (Funk et al, 1987), whereas longer dry periods are economically inefficient (Dias and Allaire, 1982) and may lead to excessive body condition at calving (Morrow, 1976). The transition period in the last 3 weeks prepartum is critical. This late dry period requires a diet considerably different in energy and protein density than phase 4. The fetus is growing rapidly, and the mammary gland is rapidly generating milk secretory tissue. The requirements for glucose and amino acids are increasing dramatically. All of this is superimposed on an animal where the DMI is usually declining. Within the last 5 to 7 days prepartum, it frequently drops precipitously, to 10 kg/head/day or less (Grummer, 1995). Thus a diet with greater energy and protein density is needed, without underfeeding fiber. The diet should contain adequate glucose precursors and an adequate source of amino acids. Beginning to feed or an increase in the amount of concentrates in the ration at this time is desirable, both to increase the energy concentration of the diet and to help the rumen adapt to a higher concentrate diet by bacterial adaptation and increasing papillae growth. Recommended nutrient concentrations for both phase 4—the far-off dry cow—and phase 5—the transition cow—are shown in Table 11-1.

Trace mineral and vitamin nutrition of dry cows is often inadequate. Antioxidant requirements—vitamin E and selenium—are probably similar to that of lactating cattle, particularly for the transition cow. High levels of vitamin E supplementation (1000 IU/day) during the dry period have been shown to substantially reduce the risk of mastitis after calving. Inadequate vitamin D may contribute to parturient hypocalcemia. Other trace mineral and vitamin supplementation levels should be adequate. Suggested guidelines are listed in Table 11-1. Inadequate supplementation may reduce expenses temporarily but is likely to result in increased rates of retained placenta, stillbirths, and other health problems.

Macromineral intake recommendations have changed in recent years. Restricting calcium during the dry period, particularly the last 3 weeks prepartum, has historically been advocated as a means of reducing the incidence of parturient paresis (Gerloff and Herdt, 1985). More recent research has suggested the anionic-cationic balance is much more important in preventing parturient paresis than the calcium concentration of the diet. Diets high in cations—sodium and potassium—are alkaline and tend to result in a high incidence of hypocalcemia and parturient paresis. Diets relatively high in the anions chloride and sulfur are acidic and tend to reduce the incidence of hypocalcemia and parturient paresis (Oetzel, 1993). The dietary cation-anion difference (DCAD) is a calculation that can be determined and manipulated to make an acidic diet during the last 3 weeks prepartum to prevent hypocalcemia. High-quality alfalfa has long been avoided during the dry period as a feed likely to result in a higher rate of parturient paresis. It now appears its potassium content is more likely responsible for the problems than its calcium content (Goff and Horst, 1996, 1997). Addition of feeds or salts high in sulfur and chloride during the transition period may allow a higher potassium feed such as alfalfa to be fed during the dry period without significant risk of hypocalcemia. A more detailed discussion of DCAD can be found in the section on metabolic disease.

The nutrient needs of the dry cow are critical and should be delivered and monitored carefully. Separate dry cow diets should be provided to the far-off dry cows and the close-up dry cows to meet their specific nutritional needs.

METABOLIC DISEASES AND NUTRITION

The complexities of the ruminant digestive system and the significant metabolic work that a lactating dairy cow is expected to perform, result in a susceptibility to a relatively large number of metabolic disturbances, or metabolic diseases. Despite an improved understanding of the mechanisms of these diseases, incidence rates remain high, particularly for displaced abomasum and ketosis (Herdt and Gerloff, 1999). Diseases commonly viewed as metabolic diseases with a nutritional cause include retained placenta, ketosis, hepatic lipidosis, parturient paresis (milk fever), displaced abomasum and rumen acidosis.

Retained Placenta

Expulsion of the placenta is a complex cascade of events that begins with the breakdown of the caruncle-cotyledon junction and ends with uterine contractions to expel the placenta within 12 hours of delivery of the calf. Retained placenta can occur when there is a failure at any one step in this process. Failure to expel the placenta frequently is associated with other, more severe consequences to the animal, including extended days open, ketosis, and displaced abomasum (Curtis et al, 1985). Twin births frequently result in retained placenta, as does induction of parturition. A normal rate of retained placenta has been reported as <15% of calvings. Rates higher than this should trigger an investigation of the dry cow diet, both close up and far off. Nutritional causes of retained placenta include inadequate selenium supplementation. Inadequate antioxidants may play a key role in the pathogenesis of retained placenta, as vitamin E supplementation also appears necessary for normal placental expulsion. Recommended dietary intakes of these nutrients for the

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dry cow are >3 mg (>0.3 ppm) selenium and 1000 units/day vitamin E. Inadequate vitamin A supplementation has also been linked to an increased incidence of retained placenta. Recommended dietary amounts are >100,000 units/head/day supplemental vitamin A. Retained placenta has also been shown to be epidemiologically related to hypocalcemia and parturient paresis. Reducing hypocalcemia by feeding anionic salts during the dry period also improved subsequent production and reproductive performance (Beede et al, 1991). Thus effective strategies to prevent hypocalcemia are important in the prevention of retained placenta, and a high rate of retained placenta within a herd should trigger an assessment of the effectiveness of the dry cow diet in preventing clinical or subclinical hypocalcemia. A variety of trace minerals may also be necessary for the normal process of placental expulsion, and an elevated rate of retained placentas within a herd should prompt an evaluation of the total vitamin and mineral supplementation program.

Parturient Paresis and Hypocalcemia

Parturient paresis, or milk fever, occurs around the time of parturition when a dairy cow's blood calcium concentration drops so low that muscle and nerve functions are compromised. It has been recognized in the veterinary literature for at least 100 years. Early on, intravenous calcium was recognized as an effective treatment, and it was slowly recognized that the condition developed because of an inability of older, high-producing dairy cattle to maintain their serum calcium concentrations in an acceptable range under the pressure of rapid initiation of milk secretion. Historical preventive strategies have focused on restricting calcium intake during the dry period. These strategies have been only sporadically effective, except when calcium is severely restricted (<30 g/head/day) (Wiggers et al, 1975), which is difficult to achieve with common feedstuffs and probably undesirable for an extended period of time.

More recently, the tendency of the diet to be acidic or basic has been recognized as having a more profound influence on the development of hypocalcemia and parturient paresis. Diets that are slightly acidic promote calcium absorption from the intestine and bone and calcium excretion in the kidney (Fredeen et al, 1988). These diets thus act to stimulate the calcium homeostatic system, and when it is challenged at the time of parturition, calcium levels can remain within the desired range. This appears to be true provided dietary calcium levels are adequate; otherwise there is a risk of depleting bone calcium. Alkaline conditions, on the other hand, inhibit calcium absorption from the intestine and bone and thus favor the development of hypocalcemia around the time of parturition (Goff and Horst. 1998). Diets high in cations (sodium and potassium, for example) cause a slightly alkalinizing effect on the body. Diets higher in anions (chloride and sulfur) produce a slightly acidifying effect. The DCAD has been used as a calculation to assess the acidifying or alkalinizing effect of the diet. One method of calculating it is shown in Box 11-4. It has been suggested that achieving a negative DCAD, in conjunction with feeding >120 g Ca/head/day, is an effective method of manipulating the phase 5 diet to prevent parturient paresis and subclinical hypocalcemia (Oetzel, 1993). Since many grass and most alfalfa forages are relatively high in potassium, achievement of a negative DCAD with them in the diet requires addition of acidic salts high in chloride or sulfur. Most of these salts are unpalatable, and care must be taken when feeding them that appetite is not suppressed significantly. Some by-products high in chloride and sulfur are more palatable than the anionic salts and are currently being marketed for the purpose of preventing hypocalcemia. Monitoring of urine pH may be an effective method of monitoring the effectiveness of dietary manipulations to acidify the diet to prevent hypocalcemia. A sufficiently acidic condition may be achieved when urine pH is <6.5 (Jardon, 1995). Because this practice stimulates bone resorption of calcium, as well as intestinal absorption, it should be emphasized that dietary calcium levels need to be maintained >120 g/head/day while a negative DCAD diet is being fed. For similar reasons, a negative DCAD diet should probably be fed only during the prefresh period (Phase 5)—not the entire dry period. A more conventional dry cow diet with a calcium content 80 to100 g/head/day may be effective at preventing parturient paresis and clinical hypocalcemia if dietary potassium levels are low (<1.2% of DM). Parturient paresis should occur in <5% of calvings. Prevention of subclinical hypocalcemia is also important because of its association with other metabolic diseases, particularly retained placenta and displaced abomasum.

Ketosis and Hepatic Lipidosis

Ketosis and hepatic lipidosis are metabolic diseases of excessive fat mobilization. They represent points on a fat mobilization continuum that includes the normal periparturient cow, a cow with subclinical or clinical ketosis, and a cow with hepatic lipidosis (Herdt and Gerloff, 1999). As such, the discussion will, in most cases, refer to both ketosis and hepatic lipidosis concurrently.

During the last few weeks before calving, the metabolic requirements of the cow change at an accelerated rate because of the rapid growth of the fetus and the initiation of milk production. Glucose and amino acid requirements, particularly, increase. Immediately after parturition, with a dramatic increase in milk production, the requirement for free fatty acids also increases dramatically. (Bell, 1995). These escalating energy and protein requirements are superimposed on a cow with a declining DMI, which usually reaches its nadir on or about the day of parturition and then increases more slowly than the energetic requirement (Grummer, 1995). Even under normal circumstances, then, a rapid rate of adipose mobilization can be expected, and a moderate increase in nonesterified fatty acid (NEFA) concentrations can be measured in the blood, beginning one week prepartum and extending for several weeks postpartum. Cows that develop hepatic lipidosis and ketosis have a greater increase in NEFA concentrations before calving than cows that do not have problems (Gerloff et al, 1986). Some of these NEFA are taken up by the liver and reesterified to triglyceride or oxidized to ketone bodies. Excessive rates of fat mobilization cause excessive liver fat accumulation and ketone production, which can further suppress appetite and interfere with normal immune function (Reid, 1980; Grummer, 1995).

Nutritional strategies to avoid ketosis and hepatic lipidosis should focus on reducing excessive NEFA mobilization from adipose tissue. Excessive weight gain, particularly during the dry period, should be avoided. If cows are obese entering the dry period, excessive weight loss should be prevented, since a starvation diet can trigger hepatic lipidosis in dry cows prepartum (Gerloff and Herdt, 1984). Thus during the far-off dry period, cows should be fed to maintain body weight with adequate allowance for fetal growth. During the prefresh transition period, diets should be formulated to provide adequate energy within the restrictions of the expected decline in DMI. Prefresh diets higher in energy concentration than current NRC requirements have been associated with reduced rates of metabolic disease and higher milk production (Curtis et al, 1985; VandeHaar et al, 1999). In the prefresh diet an energy density of 0.67 to 0.72 Mcal/lb dry

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BOX 11-4

Calculating the Dietary Cation-Anion Difference (DCAD)

The DCAD gives an indication of the acidic or basic potential of a diet. The more common calculation is the following:

$$(Na^+ + K^+) - (Cl^- + S^-), \text{ expressed in mEq/100 g or mEq/kg}$$

Na, K, and Cl are monovalent ions. S is a divalent ion. To convert dietary percentages to mEq/100 g, the following formula can be used:

$$[(\%\ Na/.023) + (\%\ K/.039)] - [(\%\ Cl/.0355) + (\%\ S/.016)] = DCAD\ (mEq/100\ g)$$

A negative DCAD diet can be fed in the prepartum transition ration, with a target value of −10mEq/100 g, or −100 mEq/kg. In the feeding of a negative DCAD diet, >120 g of Ca/head/day should be fed.

matter (1.47 to 1.58 Mcal/kg) usually requires the introduction of limited concentrate into the ration. Efforts to maximize total DMI (and minimize the decline in DMI observed prepartum) are critical in reducing fat mobilization. Other, nonnutritional factors, such as crowding, stress, heat, and water availability, can all exacerbate a DMI decline, and trigger increased rates of NEFA mobilization. Prepartum and postpartum adequate forage fiber and NDF concentrations must be provided in the diet. Inadequate levels can trigger subclinical rumen acidosis and begin the vicious cycle of declining DMI and excessive NEFA mobilization. Suggested nutrient concentrations are indicated in Table 11-1. In Canada, as well as other parts of the world excluding the United States, the feeding of monensin at approximately 300 mg/head/day, or providing it as a slow release bolus beginning 3 weeks prepartum, benefits the prevention of ketosis and improvement of milk production, at least in cows with BCS >3.5 (Duffield et al, 1999).

Normal or target incidence rates of ketosis should be <5% of cows calving. Rates significantly higher than this should trigger an evaluation of the transition cow diet, both prepartum and postpartum. An excessive drop in DMI is frequently the cause and may be influenced by other management factors in addition to nutritional ones.

Displaced abomasum

Left-displaced abomasum usually occurs early in the postpartum period. Identified risk factors include inadequate dietary fiber, presence of retained placenta, delivery of twin calves, hypocalcemia, and ketosis. Feeding all ensiled feeds prepartum significantly increased the risk of displaced abomasum postpartum, compared with including long-stemmed hay in the dry cow diet (Nocek et al, 1983). Evidence suggests that many cases of displaced abomasums are preceded by ketosis, rather than followed by it. Prevention of the initial ketosis should reduce the incidence rate of DA. Abrupt feed changes, particularly an increase in concentrate level, can trigger a DA, too. Less than 5% of cows calving should develop a DA. Prevention should focus on providing adequate long-stemmed hay prepartum, and transition diets prepartum and postpartum, which are balanced to avoid ketosis, retained placenta, and hypocalcemia. Energy density should be adequate and still provide adequate fiber to avoid rumen acidosis.

Rumen Acidosis

Lactic acidosis, or grain overload, has long been recognized as an acute clinical syndrome that occurs because of an abrupt increase in grain intake. In the unadapted rumen, the starches and sugars are rapidly fermented to lactic acid, which accumulates. This accumulated lactic acid profoundly depresses rumen pH and can represent a life-threatening situation to the animal. Sequelae in animals that survive can include rumen ulcers, hepatic abscesses, and laminitis (Nocek, 1997). Prevention focuses on making ration changes gradually (<10% increase in energy density in any one step) and on keeping below a maximum level of starch and sugar in the diet and above a minimum level of forages and NDF (Table 11-1). Subclinical rumen acidosis, not caused by lactic acidosis, is beginning to be recognized as a clinical syndrome in dairy cattle. It appears to be caused by an imbalance between the production of VFAs by bacterial fermentation and their neutralization and absorption (Nordlund, 1995). Rumen papillae in the early postpartum period have not grown physically and increased their surface area from the low concentrate diet usually present in most dry cow feeding programs. Consumption of a balanced lactating cow diet may cause more acid production (as VFAs) than the papillae can absorb, leading to a decline in rumen pH. This can affect the efficiency of the rumen, since cellulose and fiber digestion is inhibited as the pH drops below 6.2. This rumen pH decline, although not as severe a drop in pH as that occurring with lactic acidosis, may produce similar long-term effects, including laminitis, abscesses, and ulcers. Rumen pH can be measured using percutaneous rumen taps. The best time to sample TMR fed herd is 4 to 5 hours after feeding. Rumen pH values should be >5.8 (Nordlund, 1995). Too high a pH (>6.5) may indicate inadequate acid production for good performance because of inadequate carbohydrate in the diet. Too low a pH (<5.5) indicates a potential acidosis problem. Feeding strategies to avoid subclinical rumen acidosis include gradual or step-wise ration changes in which the energy density does not increase more than 10% between steps; formulation of a phase 5 transition ration that introduces carbohydrate 3 weeks before freshening to allow the papillae to begin to grow before the introduction of the lactating cow diet; adequate forage (>40% of diet DM) and adequate NDF (>28%) in the diet, with an upper limit on the amount of starches and sugars (<32%) and NFC (<42%) in the diet; and inclusion of buffers in the lactating cow diet.

Table 11-8 summarizes the more common nutritionally related diseases and their cause, occurrence, and control. Most of the major diseases with nutritional causes are avoided if attention is paid to the fundamentals of feeding dairy cows, including the provision of separate, balanced dry cow rations for far-off and close-up dry cows. Subtle inadequacies of the diet that manifest themselves in reduced production are more difficult to diagnose and correct. The best approach is to develop a program that consistently monitors the status and trends of a herd's health and productivity. Following trends provides a better indication of the herd's status and can allow intervention before a serious problem manifests itself. Good nutritional consultation is always iterative and proactive. Nutritional consultation demands a long-term commitment and relationship with the dairy producer. It is one of the most interesting opportunities available to veterinarians. Through nutrition, veterinarians can make a significant difference to their client dairies.

HEIFER NUTRITION

An adequately grown heifer, ready to calve at 22 to 24 months of age, has a significant influence on the profitability of most

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dairy herds. Delaying calving beyond 24 months of age represents an added cost to an owner of from $1.17 to $3.00 per day (Buchanan and Skidmore, 1996). Even in a small herd, this can represent opportunity costs of tens of thousands of dollars. The goal of heifers calving between 22 and 24 months of age, with a post-calving weight >250 lb (567 kg), involves several factors. Good reproductive management is essential. Breeding should begin at 13 months, with good conception rate and heat detection efficiency so that more than 75% calve by 24 months of age. To accomplish this, heifers must gain over 1.8 lb (0.82 kg)/day until 13 months of age, and continue to gain more than 1.5 or more lb (0.68 kg)/day after breeding. At one time these goals were considered too aggressive, but they are being achieved routinely today.

Earlier researchers observed that very rapid heifer growth rates (>2.2 lb [1.0 kg]/day) caused lower first lactation and lifetime milk production. These observations were believed to be related to the presence of greater fat and less DNA concentration in the mammary fat pad of heifers undergoing this "rapid rearing." This caused more fatty tissue and less secretory tissue in the mammary glands of these heifers (Sejrsen et al, 1982, 1983).

From birth until approximately 3 months of age, the mammary gland fat pad (the matrix in which the ducts of the udder subsequently develops) grows at the same rate as the body. This is referred to as a *period of isometric growth.* Then, from approximately 3 months until the onset of puberty (~600 lb [~275 kg]), the fat pad shifts to an allometric growth rate—approximately 3.5 times faster than the growth rate of the body. After the onset of puberty, the mammary growth rate again becomes isometric until influenced by pregnancy. During the allometric growth period, mammary ductular development occurs. Very rapid growth rates are believed to interfere with this critical, allometric growth phase of the mammary parenchymal tissue. Possible mechanisms include a reduction in circulating growth hormone because of the high plane of nutrition or a curtailment of the allometric growth phase because of a younger onset of puberty (Van Amburgh et al, 1992).

It should be apparent that when formulating rations for a rate of gain adequate for breeding at 13 to 15 months, care should be taken to avoid excessive weight gain (>2.2 lb [1.0 kg]/day), particularly during the prepubertal, allometric, mammary growth phase. The diet should provide adequate protein and amino acids to allow for adequate structural, skeletal, and muscle growth in addition to providing adequate energy. Maintenance of adequate protein nutrition may be a crucial aspect of avoiding the negative aspects of rapid growth on subsequent milk production.

For the first 8 to 12 weeks of life, the dairy heifer is a preruminant. Milk or milk replacer provides a significant portion of the diet. Recommendations include ensuring consumption of at least 4 L of high-quality colostrum in the first 12 hours of life—the sooner the better. Heifers should then be fed at least 12% of their body weight in milk equivalent from milk or milk replacer. For large breed dairy calves, this translates into at least 2 L twice daily of milk or milk equivalent. A high-quality calf starter should be available free choice, with a protein content of 20%. Energy requirements can vary tremendously, depending on environment. Cold, particularly, can increase the amount of milk or milk equivalent needed by 30% to 50%. Recent research suggests that limiting milk or milk replacer to current commonly recommended levels of 10% to 12% of body weight may be inappropriately reducing gains during this first 2-month period (Diaz et al, 1999). There may be physiological and economic advantages to feeding milk or milk equivalent with a high protein content at these higher rates, and relying less on dry feed consumption before weaning. More complete discussions of preruminant calf nutrition are available (Tompkins and Jaster, 1991).

Beginning at approximately 2 months of age, or 200 lb (90 kg), the concepts involved in successful feeding of dairy heifers more and more closely resemble those involved with adult cows. The rumen becomes more functional, and by 400 lb (180 kg) the calf can be considered a functional ruminant. At this point, adhering to the concept of providing adequate nutrients for maximum rumen performance applies to heifers as well as cows. Before this, there are differences of opinion on the attributes of an ideal calf diet, particularly in the recommended forage content. Some advocate little or no use of silages before animals weigh 300 to 400 lb (135 to 180 kg), and others advocate high quality fermented forage immediately after weaning. Many successful heifer-raising programs are successfully incorporating silages into rations for heifers immediately after weaning. These successful programs are marked with excellent quality forages, however, and this young calf should receive only excellent quality feed and forage. It is also well established that the stimulus for the development of the rumen in the young calf is not forage but VFA production (Bovine Alliance on Management and Nutrition, 1997). As such, palatable, fermentable calf starters are much more important in establishing good rumen development than the inclusion of forages in the diet.

Because energy is used for gain, maintenance, and lactation with different efficiencies, the net energy evaluation system describes heifer diets differently than lactating cow diets. Energy is expressed as net energy for maintenance (NEm) and net energy for gain (NEg). The energy available from a diet first is allocated to provide for maintenance needs, and only then is it available for gain or growth. The biological reality is not quite that simplistic, but this has provided a useful framework for balancing and evaluating growing and gaining cattle diets. Recommended dietary guidelines for heifers from 200 to 1350 lb (91 to 612 kg) are provided in Table 11-9. These guidelines should provide adequate nutrients for gains between 1.8 and 2.0 lb (0.8 to 0.9 kg)/day—adequate for breeding at 13 to 15 months of age and for calving at 22 to 24 months. An ionophore such as monensin or lasalocid should be included in the diet of growing heifers to improve feed efficiency.

The veterinarian can help provide a vital role in monitoring the effectiveness of the heifer nutrition programs on their clients' farms. In many cases this may involve just helping to systematize a method for comparing growth to standards at selected management events such as brucellosis vaccination, breeding, and calving. If there are significant differences in age or size at these selected events compared with recommended standards, then a more complete evaluation of the heifer operation is indicated. Monitors of growth should focus on height and body condition. Measuring only weight may obscure the development of fat heifers with inadequate skeletal growth. The reader is referred to Chapter 9 for heifer growth charts and standard curves, as well as additional information on heifer nutrition and management.

Heifer raising costs represent a significant overhead expense of most dairies. Assistance in formulating, evaluating, monitoring, and implementing a good nutrition program for heifers is a valuable service the veterinarian may provide their clients.

CONCLUSION

Nutrition and feeding programs play a pivotal role in the daily activities, economics, animal health, survival, and profitability of every dairy herd. Veterinarians must become actively involved in the nutritional programs of herds they serve. If veterinarians focus only on the results of nutritional

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TABLE 11-9

Heifer Ration Guidelines for Calving Large Breed Dairy Cattle at 22 to 24 Months

Weight (kg)	Dry matter intake (kg)	Neg (Mcal/kg)	Crude protein (CP) (%)	Undegradable intake protein (% of CP)
90-180	3.2-4.1	1.14-1.23	17	35-45
180-270	4.5-6.4	1.06-1.14	16-17	35-40
270-360	6.4-8.2	0.92-1.00	15-16	25-35
360-450	8.2-10.9	0.84-0.92	14-15	15-20
450-615	11.0-15.9	0.66-0.77	12-14	10-15

Adapted from Van Amburgh, Galton D, Fox D, et al: *Feedstuffs* April 6:12-17, 1992.

mismanagement (disease) without attending to the fundamental nutritional cause, they are not providing a complete animal health and production veterinary service. Nutritional consultation provides an opportunity for veterinarians to have a large influence on the dairy herds they serve. Dairy practitioners must make the effort to acquire the knowledge, skills, and experience required to provide a profitable nutritional health and production management veterinary service. Providing a role as an informed professional on a team of advisors to the dairy is an opportunity for which the veterinarian is well suited.

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CHAPTER 12

Housing and Environment for Dairy Cattle

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Buildings and equipment on a dairy farm facilitate the job of caring for the animals. They are the tools that allow essential tasks prescribed by the management plan to be carried out on a regular basis. Creation of an environment that meets the needs of the animals being housed is essential also. Calves, heifers, and cows require an environment that permits them to grow, mature, reproduce, and maintain health. If the basic needs of the animals are not met, no amount of management can guarantee success. Management requirements and animal environment along with labor requirements, flow of animals and materials, pollution control, and future expansion are important considerations in design.

Decisions about new or changing facilities are difficult. Facilities are expensive, and the required capital investments do not occur uniformly over time. Coupled with the fact that the farmer must live with the consequences of decisions about facilities for many years makes the process even more difficult. Thus long-range planning is important to changes in facilities, as it is to all aspects of a dairy operation.

PLANNING FOR MANAGEMENT

A prerequisite to contemplating any change in facilities is to have in hand a current management program for the farm. This management program consists of a planned series of actions based on current recommendations as applied to a specific situation (in this case, the particular farm). The program sets forth all factors related to nutrition, health, and growth as well as all other activities of the dairy farm operation. An awareness of the current recommendations of all of the experts is essential. More importantly, since no single program suits everyone, decisions must be made as to how each of these current recommendations applies to the particular farm and, if it does apply, how it will be implemented.

Style of Management

Ideally, the management program is based on a management style befitting the dairy farmer and farm family. Style of management reflects values held as well as attitude, outlook, viewpoint, and philosophy. Just as there are differences in dairy farmers, there are differences in their style of management. For example, a dairy farm based on total confinement of all ages and groups of animals is based on a style of management very different from a dairy farm based on rotational grazing and seasonal calving. Neither one can be judged right or wrong, good or bad, or superior or inferior. But in each case the dairy farmer must consciously determine and be committed to the style of management on which the system is based. For each to be successful, decisions about management must be made with full awareness of eventual consequences.

Different types and combinations of buildings and equipment are appropriate for different styles of management. Therefore, if investments in facilities are to be wise investments, decisions about facilities must be preceded by a conscious determination of management style and practices.

The buildings and equipment that comprise dairy facilities are merely tools that allow essential tasks prescribed by the management plan to be carried out on a regular basis. The buildings and equipment on the dairy farm, in fact, make it possible to implement a management program. Haphazard planning or impulsive acquisition of buildings or equipment will lead only to facilities that impede implementation of updated management plans and hinder future development and expansion.

Management Groupings

Viewing the dairy herd as a series of management groups is the primary basis for a management program. A group is simply a collection of animals that have similar needs in such areas as nutrition and environment, so similar that these animals can be viewed collectively. In terms of day-to-day management, each animal in the group can be thought of as the same. As herd sizes grow, it becomes simply too much to think about every animal every day.

Table 12-1 gives typical management categories for dairy herds of various sizes. The table can help to determine management strategies for the different groups in the management plan. Eventually, the table can serve as a guide when determining housing needs. The numbers in the table are approximations. You may need to adjust certain numbers to fit a particular management plan, because a plan may depart from the criteria set forth in the footnote to Table 12-1.

View the groupings in Table 12-1 from the standpoint of the management concepts to be limited, not as rigid rules. Some management groups may be housed in the same building, or separate facilities may be provided for each group. Regardless, allow for implementation of appropriate management recommendations for each group. Also allow for different requirements for sanitation, environment, and other factors that will affect housing design.

ANIMAL ENVIRONMENT

A goal in housing design is to provide an environment for an animal that has a positive influence on the animal's health, welfare, and productivity. Essentially all aspects of the animal's surroundings and activities are taken into account. For purposes here, environmental considerations include ventilation, stalls and beds, access to feed and water, and walking surfaces. Each of these factors is directly associated with housing design and management.

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TABLE 12-1

*Typical Management Categories of a Dairy Herd**

Herd Size = Total Cows	100	250	400	800
CALVES AND HEIFERS (age in months)	**100**	**250**	**400**	**800**
0-2	8	20	32	64
3-5	12	31	48	96
6-8	12	31	48	96
9-12	18	43	72	144
13-15	12	30	48	96
16-24	38	95	152	304
DRY COWS	**17**	**42**	**68**	**136**
Transition (first 4-14 days dry)	1-5	4-9	5-16	9-32
Next 40 days ± (divide in 2 groups)	11-12	28-30	45-48	90-96
Close-up (2-3 weeks prepartum)	4-6	8-14	16-24	32-42
MATERNITY (NO. OF INDIVIDUAL PENS, AVERAGE STAY 5 2 DAYS MAX.)	**4-6**	**5-8**	**6-10**	**8-12**
FRESH COWS (1 TO 7 DAYS POSTPARTUM)	**1-4**	**2-5**	**4-12**	**8-20**
TWO-YEAR-OLDS (300 DAYS)†	**26-30**	**65-75**	**104-120**	**208-240**
THREE YEARS AND OLDER (300 DAYS)	**58**	**145**	**232**	**464**
High producers (120 days or less)	20-24	52-60	80-96	160-192
Medium producers	15-18	40-45	60-72	120-144
Low producers	15-18	40-45	60-72	120-144
SICK COWS	**0-5**	**0-12**	**0-20**	**0-40**

*This is only a management guideline. Numbers refer to animals in categories and not group sizes. Numbers assume uniform calving year-round, 12 months calving interval, first calving at 24 months of age, all males sold at birth, a 30% culling rate, zero mortality, and a stable herd.
†Number of days of lactation.

Ventilation

Ventilation permeates all aspects of the animal environment. Most often, ventilation is associated with respiratory health of animals. Of course, the quality of the air animals breathe directly influences animal health and disease. But ventilation—directly and indirectly—affects many other aspects of animal health as well. Good ventilation in the freestall area of the lactating cow helps to keep bedding dry, a factor in favor of good udder health. Good ventilation along alleys helps to keep walking surfaces dry, a condition that contributes to healthy feet. Good ventilation may lead to greater productivity (e.g., maintaining air movement in the area of the feed manger makes the cow more comfortable), especially important during hot weather as an aid to maintaining dry matter intake (DMI). A comfortable, well-ventilated stall area encourages animals to lie down, an important contribution to many aspects of animal health.

During ventilation, outside air is brought into a barn where it collects moisture, heat, and other contaminants, all produced by the animals. Air is then exhausted to the outside. Ventilation is an air exchange process in which contaminated air inside the barn is exchanged for fresh outside air. To determine ventilation rates, veterinarians focus on the moisture content of the air, measured by relative humidity. But moisture is only one aspect. Ventilation removes other undesirable contaminants as well.

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Air Quality

Animal health and disease are influenced by air quality. Air quality, in turn, is related to ventilation and its impact on removing contaminants from the air. Empirical observations and field trials suggest that the aerosol spread of pathogens between animals and the influence of air pollutants on pulmonary defense mechanisms are important, especially to respiratory health. Excess moisture, gases, and other contaminants in the air are considered to be problematic as well. But the exact relationship among these factors is not fully understood.

The term *air quality* itself is not easily defined. With respect to animal spaces, good air quality generally implies that the characteristics of ambient air bear no harmful effects on the animals in the space. Actually, the ambient air itself is not at issue—the contaminants in the air are. Ambient air, in itself, begins as a mixture of clean, dry air (a mixture of gases, chiefly nitrogen and oxygen) and varying amounts of water vapor. When moisture in the air in an animal space is considered to be a problem, it is actually the concentration of moisture in the air above some arbitrary level that is of concern. Above some concentration, moisture can be considered an air contaminant. Other contaminants may include pathogens, harmful gases, dust, and undesirable odors. The contaminant itself does not give rise to concern. Rather, it is the concentration of a contaminant above some predetermined level that causes concern. Thus, for purposes here, it is the concentration of each of these contaminants that will be considered when assessing air quality.

Many animal pathogens apparently are spread by the airborne route (Constantine, 1969), and concentration is a factor. The bacterial content of the air in cattle barns can be as high as 10^6 organisms/m^3 and many of these are potential pathogens (Fisher, 1976). Numerous viral pathogens also are known to survive in aerosol (Donaldson, 1978). Two factors can be significant in the relationship between microbial aerosols and disease incidence: the survival duration of the aerosolized pathogen and the total number of pathogens per volume of air or concentration. Survival is influenced by conditions of the ambient air and concentration relate to ventilation.

Relative humidity is the most important factor influencing pathogen survival, but its effects vary greatly between pathogens—some survive best in humid conditions, others survive best in dry air (Donaldson, 1978). Note that, with respect to air quality and animal health, the influence of relative humidity on concentration of pathogens is important.

Maintenance of a relative humidity in the range of 55% to 75% apparently produces the shortest survival time for the greatest number of potential pathogens. Ventilation is used to remove moisture from an animal space with the intention of maintaining relative humidity in this range. In effect, inside air is diluted with outside air and, in the process, concentrations of moisture in inside air are reduced. Interestingly, continuous replacement of contaminated air with fresh outside air is also the most effective way to reduce the concentration of aerosol pathogens.

Reduction of the concentration of any air contaminant, including gases, is important to decrease its detrimental effect. For example, ammonia is produced by the decay of feces and urine and is probably the most significant air pollutant in cattle barns (Marschang, 1973). If ammonia is allowed to accumulate, its irritating effects on the respiratory epithelium apparently directly reduce the number of ciliated cells and thus decrease the efficiency of mucociliary transport (Marschang, 1973; Kilburn, 1967; Gosselin, 1966).

Dilution Effect of Ventilation

Ventilation is truly a process of dilution. Air moved through a barn actually serves to dilute the inside air and, very importantly, to dilute all of its components. Dilution reduces concentrations of moisture and heat. Dilution reduces concentrations of airborne disease organisms, harmful gases and dust, and undesirable odors as well. According to Curtis (1983), one air change can theoretically reduce the concentrations of air pollutants by 63.2%.

Conversely, concentrations of air pollutants increase when ventilation is lacking. As much as a 7.8-fold increase in airborne bacteria occurred when the outlet ventilation openings in a 15-stall dairy barn were closed (Malecki et al, 1993). Odors also increase and, in fact, can be an important indicator of the poor air quality that results from underventilation. Terms like *barny, close,* and *stuffy* are sometimes used to describe the environment inside a barn that is suffering from underventilation and poor air quality.

The concentrations of gases are related to ventilation. An Alberta study of air quality in six freestall barns found that average ventilation rates could, in fact, be estimated by measuring building carbon dioxide concentrations (Clark and McQuitty, 1987).

When ventilation is reduced below recommended levels—usually in a misguided effort to warm the barn using animal heat—less moisture is removed. Sometimes the consequences of the resulting moisture buildup and lack of proper ventilation are masked by (1) insulating the barn, (2) using a greenhouse effect, (3) providing supplemental heat, or (4) dehumidifying the inside air. For example, as explained later, the addition of heat to the air reduces relative humidity, without the need for air exchange. It is quite possible to have substantial quantities of moisture added to the air and, if accompanied by heating of the air, have the relative humidity remain in an acceptable range. Thus, if relative humidity is the only measure of air quality, air quality may be deemed satisfactory. But even though excess moisture may not be apparent, the reduced dilution does indeed cause increased concentrations of airborne disease organisms, harmful gases and dust, and undesirable odors. If these increases are ignored, animal health problems are inevitable.

Essential to maintenance of a healthy animal is providing an environment that does not needlessly stress or challenge the animal. Maintenance of good air quality is a fundamental aspect of that healthy environment with ventilation providing the key. But air quality is more than just measuring relative humidity. Through ventilation the air inside the barn is continually diluted, assuring that the air the animal breathes has low concentrations of all contaminants that threaten the animal's health.

Air-Water Vapor Relationship

Because ventilation involves moisture in the air, relative humidity—a measure of the concentration of moisture in the air—is of primary interest. Understanding the relationship between relative humidity and ventilation is helpful to comprehending the ventilation process itself.

Relative humidity expresses, as a percentage, the relationship between the amount of moisture present in a quantity of air and the amount of moisture the air is capable of holding. For example, if the air in a room is at 40% relative humidity, 40% of the moisture-holding capacity of the air is occupied (Fig. 12-1). Considering the example from the standpoint of ventilation and the need to pick up moisture, 60% of the air's moisture holding capacity remains. If no air exchange occurs, the air can take on moisture only until its

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relative humidity reaches 100%. Thus ventilation requires continuous air exchange, and the rate of exchange must be sufficient to maintain relative humidity below 100%. A range of 60% to 75% is preferred for animals.

The relative humidity of a quantity of air depends on temperature. This fact is useful in controlling the ventilation process (Fig. 12-2). As moist air is warmed, its moisture-holding capacity increases markedly. Although the air expands as it is warmed, its moisture content, expressed in absolute terms, does not change; relative humidity therefore drops. This warmed air of lower relative humidity becomes more able to pick up moisture.

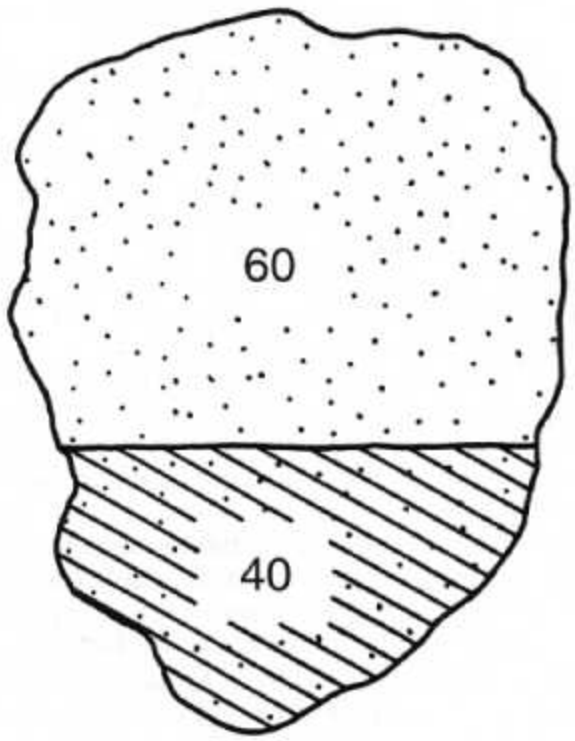

FIG. 12-1 Illustrated quantity of air at 21° C and 40% relative humidity; 40% of the air's moisture holding capacity is occupied, and 60% remains.

For example, if typical outside winter air at −18°C and 80% relative humidity is used for ventilation (Fig. 12-3), this air will not be very useful for picking up additional moisture and certainly not for achieving a relative humidity of less than 80%. But if this air is used for ventilating a warm calf barn kept at 7° C, the air will be heated to 7° C as it mixes with inside air and passes through the barn, reducing its relative humidity to about 10%. From the standpoint of ventilation for moisture control, heating the air increases its moisture-holding capacity. What remains is to carefully balance the calves' moisture production rate, the rate at which heat must be added to the air, and the necessary ventilation rate so the resultant relative humidity in the calf barn is controlled at 60% to 75% and the desired temperature is maintained. This is the basis for determining the minimum continuous ventilation rate for moisture control.

If calves are to be kept in a warm barn (e.g., 10° C), supplemental heat must be provided. Calves simply do not produce enough heat to properly warm the amount of ventilation air that is required to remove the moisture they produce. On the other hand, mature cows do produce substantial amounts of heat in relation to their moisture production. This heat, when used to warm the ventilation air required for moisture removal, allows stanchion and tie-stall dairy barns to be kept above freezing in the winter. But there is a limit to the temperature rise that cow heat can impart to the ventilating air. In a well-insulated tie-stall barn filled to capacity with cows, the maximum temperature rise of the

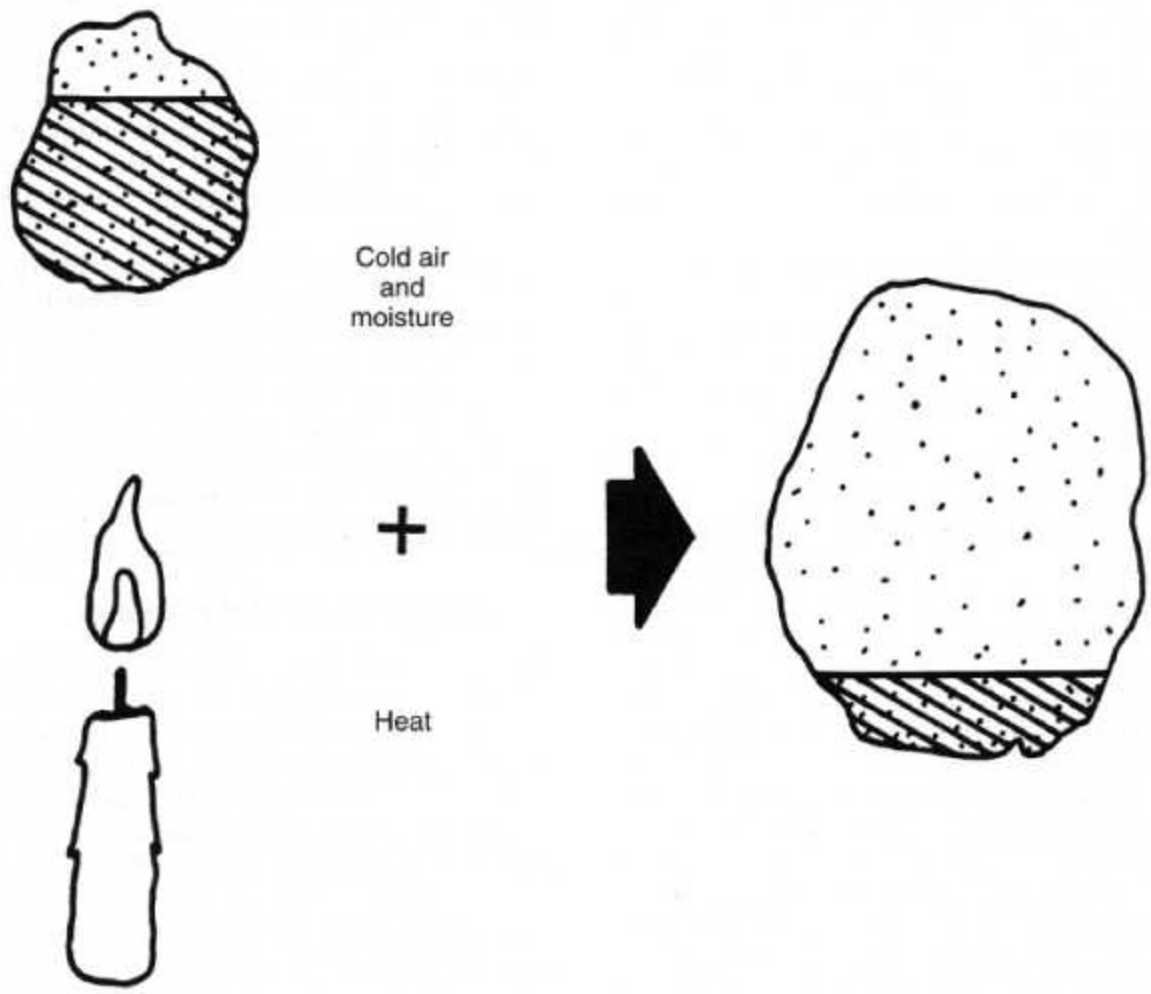

FIG. 12-2 Heating a quantity of air and raising its temperature reduces its relative humidity and increases its moisture holding capacity; the change in relative humidity is dependent on the temperature rise.

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ventilating air that can be obtained from cow heat alone is on the order of 20° K. This means that ventilation can proceed without interruption until outdoor temperature falls below about −20° C. Beyond that, the indoor barn temperature would fall below freezing and water lines would freeze, a condition that is avoided by installing a safety thermostat on the fan providing the minimum continuous ventilation.

In a cold barn the temperature rise of the ventilating air is limited to 3° to 6° K. Even so, the dependence of relative humidity on temperature is beneficial. For example, if the −18° C, 80% relative humidity outdoor air is warmed by only 5.5° K, its relative humidity decreases to less than 50%. Thus even this cold air, warmed just slightly, is useful for picking up moisture. Moreover, the heat produced by the animals themselves can cause this slight temperature rise. Care must be taken, however, to ensure sufficient air movement, preferably by natural means, to limit the temperature rise to 3° to 6° K. This is the basis for cold housing, a preferred alternative for all dairy animals.

The goal of winter ventilation design is the maintenance of good air quality for the animals. The basis for design is removal of the moisture produced by the animals themselves. Reducing the concentrations of airborne pathogens and noxious gases is important also, but if sufficient ventilation is provided for moisture control during the winter, the undesirable effects of other airborne pollutants apparently are minimized.

Minimum Continuous Winter Ventilation

A minimum rate of ventilation is required in animal housing in the winter regardless of outside temperature. This minimum rate is necessary whether the barn is designed to be a warm barn or a cold barn in winter. In addition, the minimum ventilation should be continuous. Continuous dilution of inside air acts to maintain concentrations of contaminants in the air at minimal levels. The minimum rate depends on outside weather design conditions, number and type of animals in the barn, age and size of animals, and whether the barn is intended to be cold or warm.

With mechanical ventilation, the capacity of the fan chosen to supply the minimum continuous rate should closely match the rate of ventilation that is calculated for a particular housing situation. Mechanical ventilation is most often associated with warm housing where ventilation must have a high degree of control. For certain situations the minimum rate requires a very small fan (e.g., in a warm calf barn), and a fan that small may not be available from a particular source. The practice of using a larger fan on a percentage timer should be avoided. For example, suppose that 500 l/s is the minimum continuous ventilation rate desired, but the smallest fan available is rated at 1500 l/s. Operating the larger fan one third of the time (i.e., 5 min every 15 min) produces an effective rate of 500 l/s. Unfortunately, the wide fluctuations and lack of uniformity in indoor conditions are not in the best interest of animal health. Small fans are available, but it may be necessary to search them out.

With natural ventilation, minimum ventilation is less controlled. Depending on thermal and wind forces, natural ventilation is most often associated with cold housing. As will be described in later sections, deciding between warm and cold housing is critical to the design and subsequent management of the ventilation system. Understanding the differences between the two types of environments is especially important as related to the need for maintaining the minimum continuous ventilation for winter in either situation that is in the best interest of animal comfort and health.

Barn Categories and Winter Temperatures

Barn environments can be categorized according to temperatures maintained in the barn in winter. The particular environment, based on desired indoor temperature, must be established before ventilation system design can begin.

In a *cold barn*, indoor temperatures are allowed to fluctuate with outdoor temperatures. Ventilation is sufficient to maintain indoor temperatures within 3° to 6° C of outdoor temperatures. Usually the barn is not insulated and ventilation is largely unregulated, except to adjust for seasonal changes.

Warm barns are well insulated and, by necessity, have a well-controlled ventilation system. These barns are designed to provide a relatively uniform environment throughout the winter. Tie-stall barns, where indoor temperatures are to be

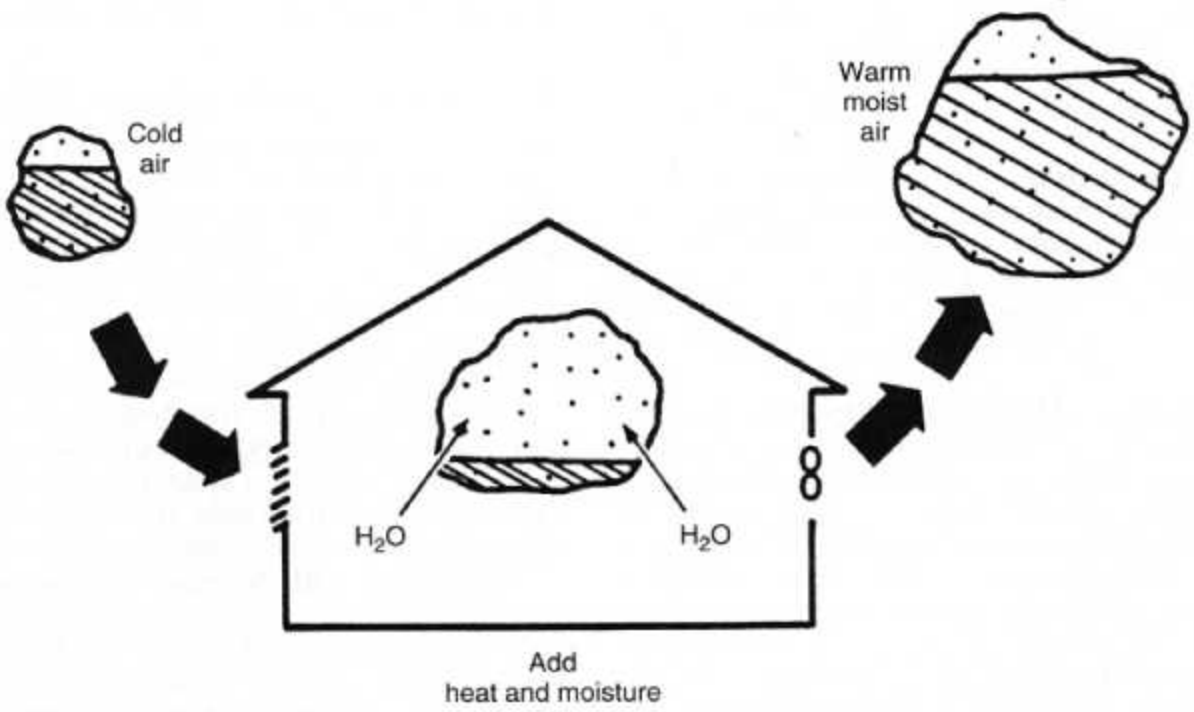

FIG. 12-3 Cold outside air with a high relative humidity can pick up large quantities of moisture in a barn if the air is heated. Even a slight temperature rise of 5.5° to 8.3° C, as can occur in cold dairy barns, is useful.

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maintained at least above freezing, remain the principal example of this type of housing for dairy animals. The key to success is ventilation that is well managed and regulated in order to compensate for changing outside climatic conditions.

Some barns do not fit into either the warm or cold category. An *in-between barn* or *modified environment barn* usually has indoor temperatures above freezing in winter. These buildings have some insulation, perhaps only under the roof, and are naturally ventilated (usually with open ridge, eaves, and sidewalls). Unfortunately, even though a minimum ventilation rate is always necessary, ventilation openings may be closed or blocked during extreme weather to keep manure from freezing and for other reasons. This practice can cause inside temperatures to rise 10° to 20° C above the outside temperature, significantly higher than the 3° to 6° C temperature difference limit considered acceptable for cold barns. This alone can create problems because of excess moisture buildup and a high relative humidity. But, even more seriously, openings remain closed or blocked after severe weather conditions have passed. As a consequence, blocked ventilation openings restrict airflow during less severe conditions, causing underventilation and poor environmental conditions. A properly designed and managed in-between barn is more like a warm barn, in terms of both design and operation. Thus, to avoid problems, the design and management of in-between barns should follow the guidelines for a warm barn.

Consequences of Mismanaged Ventilation in Winter

Underventilation in winter is one of the most serious threats to the environment of animals. Both improper design and improper management of the ventilation may be reasons that wintertime ventilation is lacking, compromising animal health. Problems are most likely during winter, spring, and fall, especially during rainy weather and warmer days coupled with cold nights.

Reduced Dilution of Ambient Air. A major reason for air quality problems in barns in winter is adjusting ventilation for the worst case—severe winter weather—and not readjusting to allow increased ventilation when milder winter weather appears. This is especially true for cold barns with manually controlled natural ventilation. Perhaps ventilation openings are closed in anticipation of a windy, cold, blustery night, but they are not opened the next day when, although the temperature may still be cold, the wind subsides and the sun shines. Very simply, lack of wind reduces ventilation, reducing air exchange and the positive effects of dilution.

Sometimes good ventilation system management does indeed call for openings to be reduced. For example, a slot inlet in a mechanically ventilated tie-stall barn is adjusted to match the lower ventilation rate in winter. Fabric may also be placed over on open sidewall. But openings are never completely covered that would leave no means of air exchange for moisture control.

Building Components Affected by Poor Ventilation. Besides adversely affecting the animal environment, the design and operation of naturally ventilated barns influence moisture related deterioration in wood members and metal fasteners as well. Naturally ventilated dairy barns have been studied in Michigan (Harrigan and Bickert, 1986). In barns where air exchange in winter was defeated by blocking ventilation openings, average wood moisture contents exceeding 30% dry basis (capable of supporting wood decay and corrosion in metal fasteners) were found after 2 to 3 months of cold weather operation. Moreover, restricted air movement in these barns inhibited drying and allowed wood moisture contents to remain elevated even into warm weather. Warm, moist conditions favor growth of mold, bacteria, and decay fungi and accelerate metal corrosion. The presence of insulation under the roofing in these problem barns fostered this situation.

In barns studied, moisture content rise was minimized where design details and management efforts allowed optimum air exchange rates. Even if free water from precipitation and condensation caused slightly elevated moisture contents, adequate air exchange, especially during warm weather, promoted drying of wood truss components so that deterioration was not a problem.

Misguided Use of Insulation in Cold Barns. In a cold barn the inside temperature is maintained no more than 3° to 6° K above the outside temperature in winter. Usually this is accomplished through largely unregulated natural ventilation with appropriately sized ridge and eave openings along with adjustments in door and wall openings. Adequate air exchange during cold weather to ensure moisture control eliminates the need for insulation.

If insulation is installed under the roof, a potentially cold barn may not be operated and managed as a cold barn. The presence of insulation suggests that the barn is something other than a cold barn, that an available option is to close or block ventilation openings during extreme weather conditions to restrict ventilation. The most serious deficiency associated with this approach is the lack of proper control to restore ventilation rates when extreme weather has passed. The consequences of this mismanagement are even more serious with high-producing cows because of their higher rates of heat and moisture output. For a barn with insulation to operate successfully, it must be operated more like a warm barn than a cold barn, as just discussed for modified-environment barns. Proper insulation, a high level of management, and well-regulated ventilation are necessary ingredients.

Barns with insulation under the roof are often underventilated because evidence of a moisture problem does not appear. Besides contributing to problems with animal health, underventilation can lead to the premature deterioration of structural components in buildings. Condensation on the underside of the roof of a cold enclosed barn can be considered a management tool or signal for the farmer that excess moisture buildup is occurring and additional ventilation openings must be provided for better air exchange. The presence of insulation can take away this important indicator, creating a potentially unfavorable environment!

Types of Ventilation Systems for Dairy Barns

Two types of ventilation systems are used in enclosed dairy barns: natural and mechanical. Most often, naturally ventilated barns are associated with cold housing where indoor temperatures remain within 3° to 6° K of outdoor temperatures in winter. As a cost-saving measure, natural ventilation is used for warm barns as well. But care must be taken to conscientiously adjust ventilation openings in order to avoid the problems mentioned for in-between barns where ventilation is restricted for the purpose of using animal heat to maintain higher indoor temperatures. A well-controlled mechanical ventilation system is desirable for a warm barn in order to minimize risks associated with the reduced rate of air dilution that accompanies warm housing.

Cold Barns with Natural Ventilation. In general, a cold barn with natural ventilation has these minimum characteristics: no insulation, open ridge and eaves, and sidewalls and endwalls that open. Providing an open ridge along with open eaves has long been recognized as a means of using a stack effect to cause air exchange, especially for controlling moisture in winter. Indoor temperatures are expected to be a few degrees warmer than outdoor air temperature because of

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the heat being given off by the animals being housed. Current recommendations call for providing a ridge opening of 5 cm per 3 m of barn width and equivalent open area divided between the two eaves. Raised ridge caps are to be avoided. Their performance has been unpredictable because of local wind patterns. In fact, raised ridge caps often channel winds into the structure, thereby increasing the entry of wind-blown snow and rain.

Very importantly, the combination of the open ridge and eaves can be viewed as the sole source of ventilation only during the most severe winter weather—during periods when temperatures reach the lowest levels or times when especially windy, stormy conditions are present. During all other times in winter, additional ventilation must be provided. Typically, doorways are left open for this purpose, portions of the endwall sections of the gable roof may be left uncovered, or sidewalls away from prevailing winter winds may be left open. Then, as temperatures rise into spring and summer, sidewalls and endwalls are opened fully. As a general rule, too much ventilation is preferred over too little.

In winter, air movement through the barn should be sufficient to maintain inside temperature within 3° to 6° K of outside temperature. A thermometer can be hung inside the barn. If the temperature inside is more than 3° to 6° K above outside temperature, more ventilation is necessary. Also, persistent condensation on the underside of the roof is a further indication that additional ventilation openings must be provided.

Various materials and methods are used to cover sidewalls for colder weather. Automatic control or even frequent manual adjustment of air inlets is unnecessary. The dairy cow can tolerate usual diurnal fluctuations in environment and even fluctuations during the season, especially in summer. The simplest and cheapest method of covering sidewalls uses a fabric covering over the full sidewall. For summer, the fabric is manually rolled up as a rug and tied at every post. To close the sidewall, ties are released and the hanging curtain is then fastened in place using a vertical nailing strip at each post and horizontal nailing strips all along the bottom.

Substantial areas of the triangular endwall sections of gable roofs, from the eave line to the roof line, are left open as well. These areas, well above the height of the cows, may be the last covered as winter begins and the first opened as winter abates. This ensures adequate ventilation during periods of fluctuating ambient temperatures while minimizing excessive movement of colder air in the vicinity of the animals—without frequent adjustment of openings.

Barns with open sidewalls and endwalls in summer have improved ventilation, creating lower average temperatures inside the barn in summer. However, the real advantage to the cows is related to the extremes—specifically, during the heat of the day and the cool of the night. Not only are cows exposed to lower temperature peaks during hot weather, but they are also exposed to these peaks for shorter periods of time. In addition, inside temperatures closely follow outside temperatures as they lower at night, allowing cows to take advantage of whatever cooling effect may result from lower nighttime temperatures.

Summer ventilation depends on the wind. The main factors that affect ventilation rates are area of building openings, local obstructions (hills, vegetation, nearby buildings), wind speed, and wind direction. Air exchange rates resulting from wind forces can be maximized by increasing inlet and outlet openings and by accurately locating buildings for maximum exposure to existing winds.

Warm Barns with Mechanical Ventilation. In a warm barn the indoor temperature is maintained substantially higher than outdoor temperature during winter. For example, a tie-stall dairy barn is commonly held at 5° C or higher. A swine nursery is maintained at about 30° C with the addition of supplemental heat. These buildings are well insulated. Fans with thermostat controls automatically regulate the ventilation rate as outside conditions change, diurnally and seasonally. Three levels of ventilation must be provided for year-round ventilation. Three fans can achieve this. However, with the high ventilation rates being used today, more than one fan may be used, especially to achieve the summer level. Summer ventilation rates of 60 to 90 air changes per hour are not uncommon. These levels are on the order of ten times the minimum continuous rate for winter.

Exhaust fans, sized according to the number and size of the animals present, draw air out of the building. This creates a slight vacuum or negative pressure inside the building. This pressure difference between indoors and outdoors causes air to move into the building wherever there are openings. The air inlet openings are sized and located properly so that fresh air enters the building uniformly and is mixed with the other air. Typically, an adjustable slot inlet, continuous along both sidewalls except in the immediate area of the bank of fans, distributes incoming air.

Insulation in a warm barn performs three main functions. First, insulation reduces heat loss from the building, conserving heat generated by animals and other sources inside the building for use in heating the ventilating air. Second, the surface temperature of inside wall surfaces will be higher, reducing the possibility of condensation occurring. Third, radiant heat loss from animals located near outside walls will be less with higher inside-wall surface temperatures.

Warm Barns with Natural Ventilation. Natural ventilation for warm barns came about in the interest of lowering investment and operating costs for livestock and poultry buildings. The buildings remained essentially the same with respect to insulation and a warm environment in winter. However, natural ventilation was substituted for mechanical ventilation. In some livestock and poultry buildings, mechanical ventilation was used for winter, spring, and fall, but the sidewall openings were provided to allow wind forces to produce air exchange during summer. This eliminated the need for fan operation during the time of the year when the highest rates of ventilation—and highest energy costs—would be required. In other situations, natural ventilation was to be used year-round.

Well-regulated naturally ventilated warm buildings, relying on stack and wind effects, have been successful. For example, the modified-open-front swine finishing building was designed to be a well-insulated barn with natural ventilation. Adjustable openings were provided for modulating both the stack effect and the wind effect as necessary, depending on outside conditions. The inside temperature was to be maintained at least a few degrees above freezing in the interest of maintaining feed efficiency. At the same time, ventilation was always to be maximized so as not to compromise air quality. To achieve this balance, frequent adjustments in ventilation openings are required, sometimes several times per day, to compensate for changes in outside conditions (e.g., wind velocity or direction, temperature, solar radiation). In the end, some of these modified-open-front swine finishing buildings were very successful. Some were not because the building manager either did not understand the need to frequently adjust ventilation openings in order to maintain optimum air quality or was unwilling to devote time and energy to the task. The building concept is still popular. But most buildings of this type constructed today have ventilation openings that are opened and closed automatically by various types of actuators controlled by thermostats.

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Natural ventilation for warm housing has been described by Choiniere and Munroe (1990) for buildings that are temperature controlled in cold weather. Their recommendations for construction and for sizing chimney and sidewall openings (Choiniere et al, 1994) do not apply to cold or modified environment barns where inside temperature is at or slightly above outside temperature.

Animal Lying Places

A reasonably clean, dry, resilient bed on which to lie down helps maintain a dry erect haircoat for the small calf in cold weather as well as provides the larger cow with a clean, comfortable place to lie down for rest and to relieve stress on feet and legs. A cow will lie down for longer periods of time and more total hours per day in a more comfortable stall. The outcome is longer resting time, less time for the cow to be standing in wet manure, and more drying time for wet feet.

Bedded Areas

Loose housing of dairy cattle on bedded manure packs with separate facilities for milking were established concepts by the middle 1950s. Of course, loose housing has long been the rule in warm climate areas with herds kept in a corral or barnyard. Even now, bedded areas are common for housing groups of young animals and dry cows; bedded pens that are frequently cleaned are recommended for calving as well. However, in most areas today, when barns are provided for lactating cows, these barns are equipped with freestalls.

Groups of animals provided with a bedded area for resting should have access to another area—an outside paved lot or a scraped alley—for feeding. This reduces the amount of manure deposited in the bedded area. Also, the problems that develop with wet, trampled bedding when the bedded area is next to the feed manger are eliminated. Recommended bedded area per animal varies with the size of the animal, from 2.4 to 2.8 sq m for calves that are 6 months of age to 4.6 to 6.0 sq m for mature cows. If cows close to calving are housed on a bedded pack, the bedded area should provide at least 9.0 sq m per cow.

Freestalls

A Washington dairy farmer, Adolph Oien, is credited with developing the freestall when in 1959 he installed a series of individual stalls in a loose housing shed. Adoption of the idea was rapid. In fact, an article in the January 25, 1963, issue of *Hoard's Dairyman* magazine reported that the freestall system was the subject of more inquiries and comment than any recent development in dairy farm management.

Basis for Freestall Design. Cleanliness and comfort are two basis prerequisites that must be satisfied in freestall design and construction. Cleanliness relates to clean, dry conditions, especially a clean, dry stall bed in the vicinity of the udder. Comfort means a comfortable bed to allow the cow to lie comfortably in the stall along with roomy dimensions that make it easy for the cow to enter the stall, lie down, rise, and exit. In simplest terms the main purpose of a freestall is to reduce exposure of the teat ends to mastitis causing organisms. What follows is to make the stall so appealing that a cow chooses no other place but a freestall to lie down 10 to 14 hours per day.

A freestall should enable a cow to rise and lie down naturally. (See Figs. 12-4 and 12-5 for illustrations of the rising movements of a cow.) A 635-kg cow requires 168 cm for body space and about 47 cm for head space to lie comfortably. This adds up to 215 cm (7 ft), a commonly recommended freestall length. Freestalls must provide a lunge space for cows to rise. This lunge space ranges from 25 to 55 cm added onto the combined 215-cm body and head space (or, the space is 70 to 100 cm measured ahead of the foreknees). Accounting for this lunge space is the first and most important aspect of stall design and a key to providing stalls that cows will use readily.

The lunge space may be provided either forward or to the side. The option chosen determines both the type of partition to use and the overall length of the stalls. If the forward lunge is to occur within the stall envelope, the recommended length overall is at least 245 cm. Or, if space for the lunge is provided to the side into an adjacent stall space, overall stall length need be only 215 cm. Other alternatives are to allow the cow to lunge forward into a stall space opposite the cow or into an adjoining alley or even to the outside of the barn itself.

Types of Freestalls and Components. Depending on provisions for the thrust of the cow's head during the lunge, freestalls may be in one of two categories: forward lunge or side lunge. Fig. 12-4 shows two examples of forward lunge stalls; Fig. 12-5 shows side lunge stalls. Certainly other designs may satisfy the concepts and principles of freestall design equally well. Therefore an evaluation of a particular freestall begins with assessing its merits in meeting the basic needs of the cow from the standpoint of comfort and cleanliness.

Side lunge and forward lunge freestalls differ in partition shape and in stall base design at the front of the stall. Designs are similar at the rear of the stall. Both types provide space beneath the lower rail to minimize contact with the hip and pelvic area of the cow, reducing the potential for injury.

In a side lunge freestall, the cow turns and thrusts her head into an adjacent stall space as she rises. The lower rail of the partition is either high enough at the front to allow the cow to thrust her head under the lower rail or low enough to allow the cow to thrust her head over the lower rail without interference. If the cow thrusts her head under the partition rail, the bottom partition rail should be installed a minimum of 72 cm above the stall surface. If the cow thrusts her head above the bottom rail, the bottom partition rail should be a maximum of 18 cm above the stall surface. In Figs. 12-4 and 12-5, the values given for these dimensions are greater since the dimensions are measured from the top of the back curb—a more stable reference point, especially in sand-based freestalls.

In a forward lunge freestall, additional stall length is needed to allow the cow to lunge forward, either within the stall envelope or through an open front to space beyond. If the lunge is within the stall envelope, the stall must be at least 245 cm long. If the lunge is through an open stall front, a minimum of 54 cm of open vertical space must be provided.

The brisket board defines the space for the body of the lying cow and discourages her from moving too far forward into the stall when she is in a lying position. A brisket board is essential in a stall where space for the lunge is provided ahead of the cow. A neck rail across the top rail of the stall partition is important for maintaining stall cleanliness. The neck rail encourages cows to back up when rising and stops cows from moving too far forward when standing without being a nuisance to them. A neck rail that is too low hinders the rising movement. A neck rail that is too close to the curb does not allow a cow to enter the stall and stand comfortably on all four feet, a prelude to lying down. Neck rails should be 167 cm (66 in) ahead of the alley side of the curb and at least 101 cm (40 in) above the stall bed.

Each type of freestall is a unique system, depending on provisions for the lunge space, type of partition chosen, etc. All components act together, related to one another with ap-

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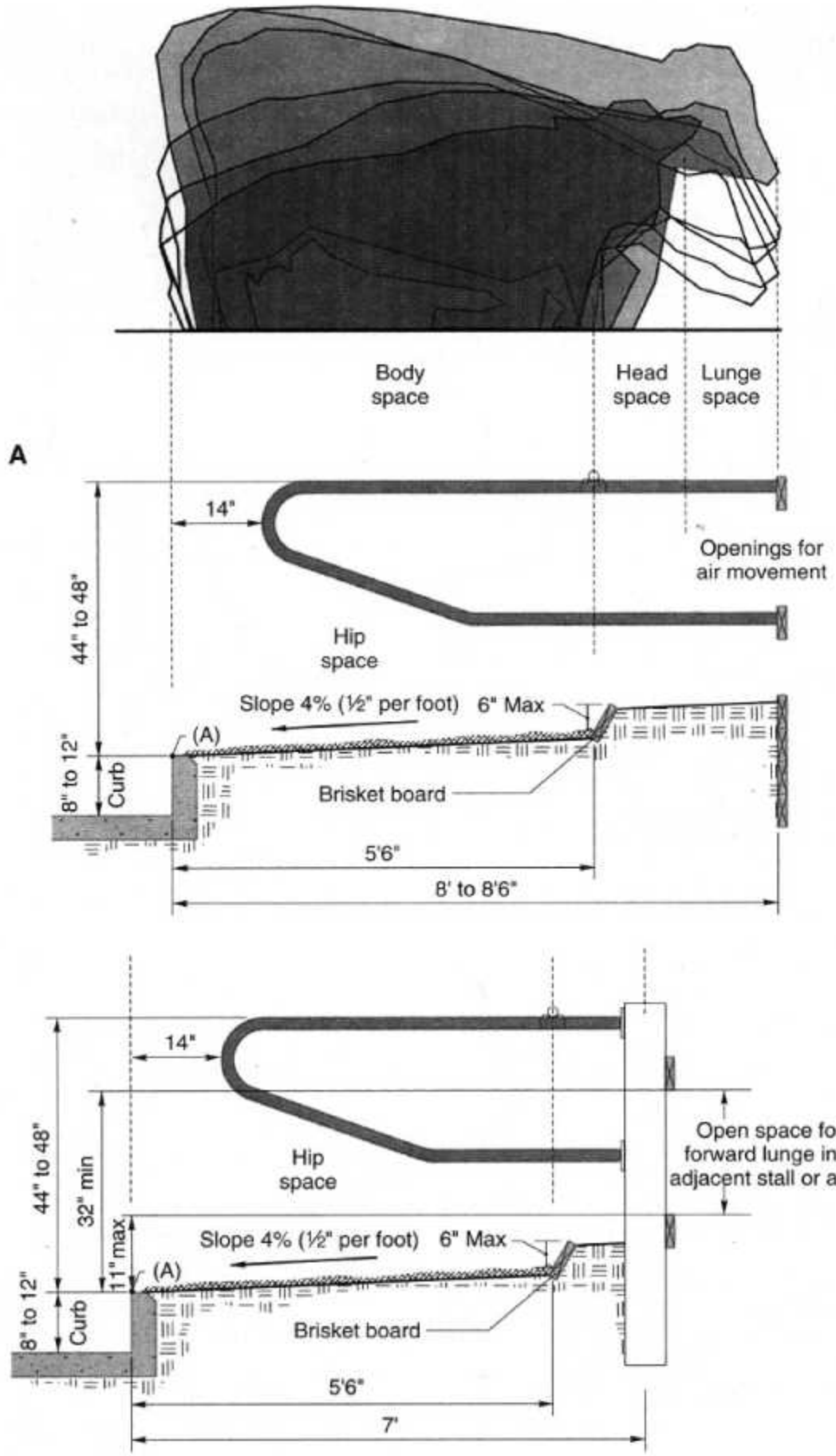

FIG. 12-4 Forward lunge freestalls. Top of curb *(A),* or apparent top of stall bed if higher, is reference point for measurements. **A,** Single loop partition. Cow thrusts head forward within stall space. **B,** Head-to-head partition. Cow thrusts forward, into facing freestall or alley, using open space at stall front. (From Bickert WG et al: *Dairy freestall housing and equipment,* ed 7, Ames, 2000, MidWest Plan Service, Agricultural and Biosystems Engineering Dept., Iowa State University.)

propriate dimensions, to provide the best environment for the cow. Arbitrary changes disrupt the system. The following is an example of when a dimension from one freestall system is applied to another.

With side lunge stalls, a cow must have easy, natural access to the lunge space. Side lunge partitions are manufactured accordingly. When the recommended freestall length is used (215 cm for a 635-kg cow), the partition is mounted at the front of the stall such that the cow can easily reach the lunge space. However, making the freestall bed longer than necessary (say 230 cm versus 215 cm) positions the partition and the lunge space 15 cm farther forward in the stall, well

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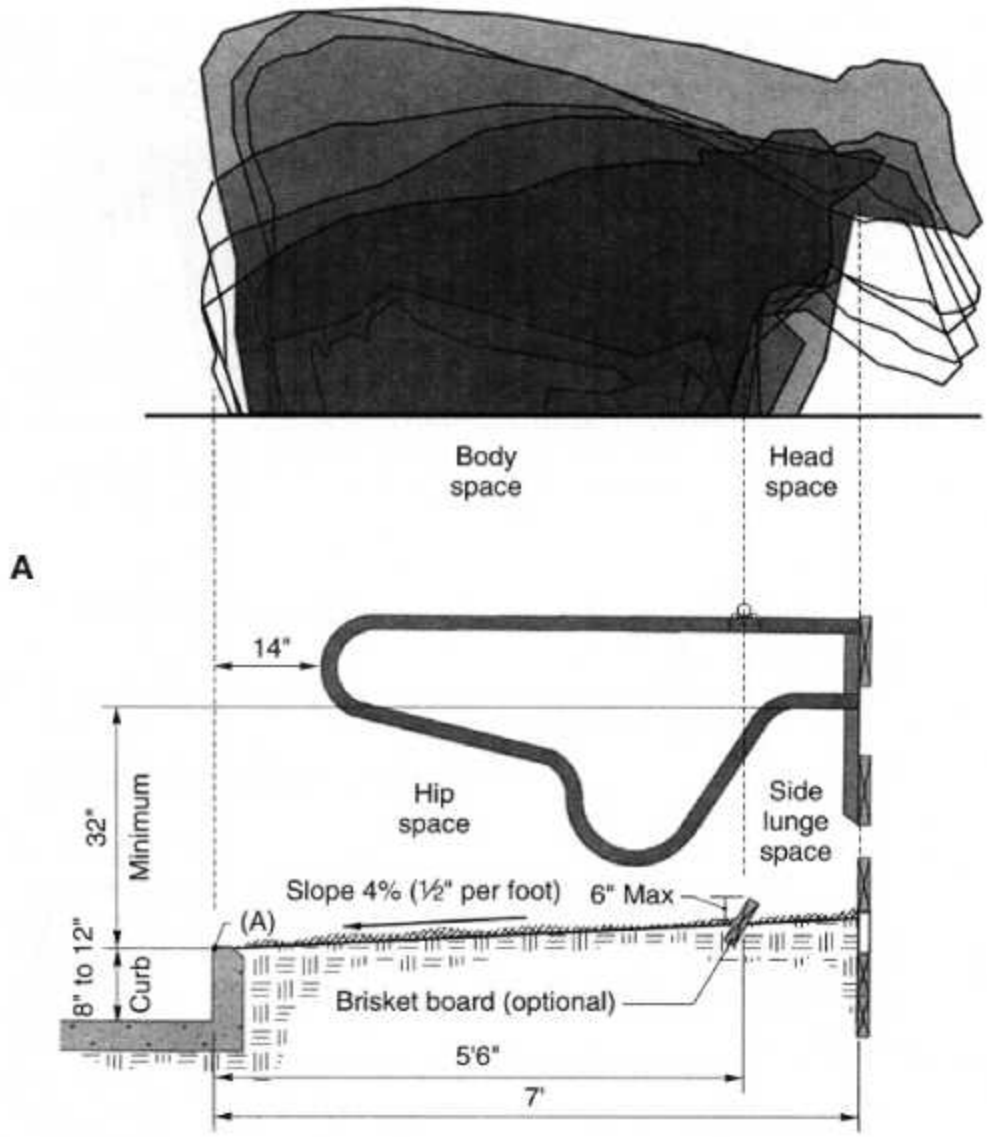

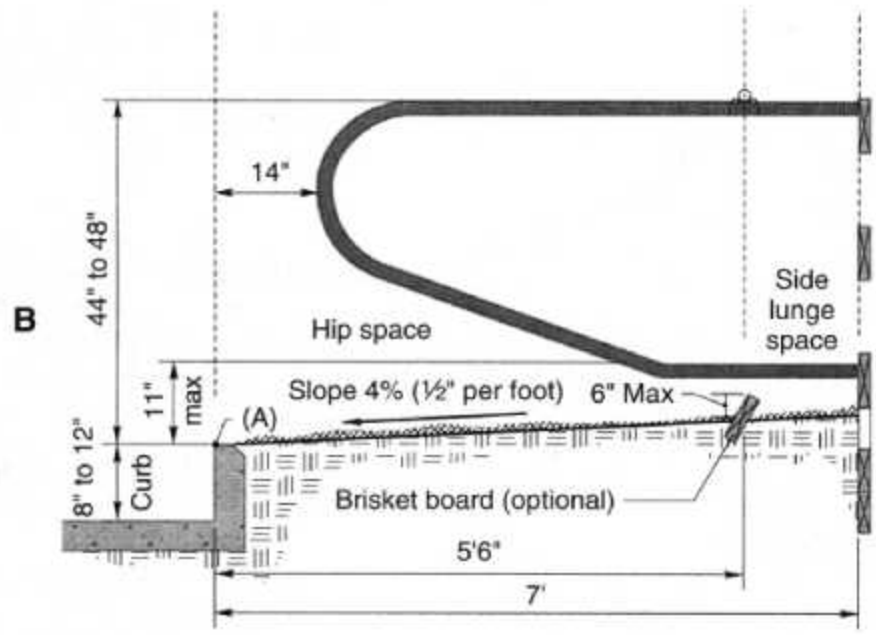

FIG. 12-5 Side lunge freestalls. Top of curb *(A)*, or apparent top of stall bed if higher, is reference point for measurements. **A,** Side lunge partition. Cow thrusts head under rail into adjacent stall. **B,** Wide loop partition. Cow thrusts head over rail into adjacent stall. (From Bickert WG et al: *Dairy freestall housing and equipment,* ed 7, Ames, 2000, MidWest Plan Service, Agricultural and Biosystems Engineering Dept., Iowa State University.)

ahead of where it should be for the cow's comfort. Without a brisket board, the cow will move too far forward in the stall, increasing the likelihood of her defecating in the stall. A brisket board will help position cows to prevent dirty stalls. But, cows will then have to reach forward awkwardly to use the lunge space in a longer stall equipped with a side lunge partition.

Recommended Dimensions. Ultimately, dimensions chosen for freestalls represent a compromise between cow comfort and cow cleanliness. Stalls must enable cows to lie down and get up naturally and comfortably. Stalls should be wide enough that cows normally do not contact stall partitions in any way that could cause injury or that could damage the partitions. However, stalls that are too wide may

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TABLE 12-2

Suggested Freestall Dimensions

Weight (kg)	Freestall Width (cm)*	Freestall Length (cm)*		Neck Rail Height Above Stall Bed (cm)	Neck Rail and Brisket Board, from Alley Side of Curb (cm)
		Side Lunge	Forward Lunge		
365-545	107-112	198	230-244	94	158
545-680	112-122	215	244-260	102	168
over 680	122-132	228	260-275	107	180

*Width: "center-to-center" with 5-cm pipe partitions; length: alley side of the curb to the front of the stall.

allow cows to turn around in them or lie diagonally. Stalls that are too long may allow lying too far forward unless brisket boards are used. All of these conditions increase the possibility of manure being deposited on the stall bed.

Table 12-2 shows a range in the recommended stall widths and lengths. The lower values of the ranges in the table represent a livable compromise between cow comfort (high rate of stall usage) and cow cleanliness. The upper values, which provide for wider and longer stalls, favor cow comfort over cleanliness and allow more time being spent in stall maintenance.

With two rows of freestalls placed head to head and designed for forward space sharing, stall partitions are usually mounted on posts. This allows for unrestricted open space for the forward lunge into the adjacent stall space. When a row of building support posts are located down the center of the two facing rows, spacing between the support posts must be a multiple of the freestall width (115 cm on center for typical Holstein herds). Otherwise, building support posts will be located periodically in the forward lunge space needed by the cow. Freestall width should determine building post spacing, not vice versa. In hot climates consideration to heat buildup in the freestall area may lead to wider freestalls (e.g., 120 cm). Although, in a well-ventilated building equipped with cooling fans, the advantage of wider freestalls has not been established.

Freestall Base and Bedding. The stall base and bedding act together to provide a resilient bed and a clean, dry surface. Of all the factors that discourage cows from lying in freestalls, an uncomfortable freestall bed is likely the most important. Beds that do not provide sufficient cushion (concrete, concrete with a rubber mat, compacted earth) often cause swollen hocks and knees. Beds with mounds, lumps, or holes reduce comfort for the cow but, worse yet, can cause difficulties for the cow upon rising. Lack of comfort and difficulty in rising both discourage freestall use. The base of the freestall should slope upward 4% from the rear to the front. A curb at the back puts the stall beds 15 to 25 cm above the alley and keeps scraped manure or flush water out of stalls.

Two methods have emerged as top candidates for freestall base and bedding: mattresses with bedding on top and a deep layer of sand. Bedding mattresses, 8 to 10 cm thick, over hard stall bases such as concrete or well-compacted earth can provide a satisfactory cushion. A bedding mattress consists of bedding material sandwiched in a fabric-heavyweight polypropylene or other material. Various materials are used as filler—long or chopped straw, sawdust, shavings, or shredded or ground rubber.

Bedding material added on top of the mattress absorbs moisture and manure tracked into the stall. Also, chopped straw or similar material on a bedding mattress acts as a lubricating layer, reducing abrasions to the skin when the lying cow tends to slide around while lying down. Dry bedding on the surface is an essential aspect of a mattress system. The use of short, fine bedding material reduces the amount of bedding material dragged into the manure alley. Choice of bedding material may influence selection of a manure handling and storage system. Too much long straw or other organic material can build up a substantial crust in a storage. A crust reduces odor from the storage but creates problems with agitation at emptying.

A bed of loose sand—15-cm minimum—maintained in the stall area can be considered as the gold standard for a freestall base and bedding. Sand contributes to cow comfort, good udder health, and clean cows. In addition, sand kicked into the alleys improves cow footing. If other materials are to be considered as alternatives and are to be evaluated on the basis of cow comfort, sand is the basis for comparison. The only logical reason for not using sand has little to do with the cow comfort and udder health, but with the difficulty it adds to the manure system or the availability of high-quality sand. Sand bedding may greatly complicate the manure handling system.

As a cushion or for resilience, loose sand conforms to the shape of body components (knees, hocks, etc.). This reduces pressure on projecting bones and body parts by distributing downward force or weight over a larger area. This is important to the lying cow; the total weight of the cow is transferred to the lying surface through the contact points of the cow's body.

Spreading the cow's weight over a larger area protects the front knees of the cow during rising also. A cow rising from a lying position lunges forward, transferring the weight of her body forward so she can more easily rise on her hindquarters. The knees act as the fulcrum for this teeter-totter action, with the stall bed providing the cushion for the knees. During the lunge the weight transfer process increases the downward force on each knee from 160 kg (about one fourth of the cow's weight) to 230 kg or more—on each knee! As the sand conforms to the shape of the knee,

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increasing the area over which this downward weight of the cow is distributed, the potential for injury to the knee is decreased.

Good footing in the freestall is essential to the cow's ability to lie down and rise easily. In this case, "footing" means not only reducing the tendency to slip but allowing the cow to more or less embed her foot in the surface in order to provide good leverage. When a cow can rise more confidently, rising time is reduced. Also, the tendency to rock back and forth is lessened, and rising is accomplished more smoothly, reducing trauma to knees, ankles, etc. Loose sand provides excellent "footing." Beds of other materials must be equivalent.

Every one to four weeks, sand is added to the front of the stall bed, leaving it to the cow to work toward the rear of the stall. The sand should not contain small rocks or pebbles, which could cause damage to the hoof or lameness. Sand should be replenished before the front of the stall bed becomes lower than the rear, a condition that makes it difficult for cows to rise and causes them to lie diagonally in the stall. A stall that is lower in the front leads to more manure in the stalls and to dirtier cows.

The search goes on for the ultimate freestall bed. Meanwhile, a bed of loose sand and rubber-filled mattresses with organic bedding on top are two methods for satisfying the requirements for freestall beds that promote cow comfort and good udder health. Sand appears to have the advantage. However, either system, properly installed and maintained, can contribute to a desirable environment for the dairy cow.

Freestall Care. Proper freestall care includes daily inspection and removal of wet bedding and manure, besides adding dry bedding periodically. Neglected freestalls with excessive moisture or accumulations of manure can lead to an increased incidence of mastitis. For stalls with bases that must be replenished, such as sand, an upward slope of the base toward the front should be maintained. This upward slope helps position cows more squarely in the stall when lying down, and this contributes to cleaner stalls and cleaner cows. Freestall hardware and other components should be kept in good repair.

Access to Feed and Water

Feed mangers and bunks have developed around two basic forms: (1) mangers where the animal eats from a surface that is at or slightly above the floor on which it stands, or (2) feed bunks where the bottom of the bunk is substantially higher than where the animal is standing. The first type has been associated with open dry-lot systems in warmer climates where the feed mangers are along a side or end of dirt lots with mobile scale-mixers usually used for feeding. In colder climates this arrangement is common in tie stall or comfort stall barns, where the feeding surface is one to two inches above the cow platform, and in free stall barns designed for mobile feeding.

The elevated type of feed bunk was clearly the choice as loose housing developed in colder climates. The most likely reason for the elevated design was to accommodate bedded manure packs. Sufficient height was necessary to allow for the manure pack to build up, not only in the pen or loafing barns but in outside lots where infrequent manure removal and accumulations of snow and ice gradually raised the elevation of the cow. In fact, construction plans for feed bunks sometimes included the recommendation to increase the height of bunks intended for use where manure, snow, or mud may accumulate. Quite possibly, the cow could end up standing on a manure pack higher than the bunk floor itself, which may have prompted Loughary and White (1950) to write: "Provide . . . adequate manger guards to prevent cows from falling into the manger."

However, cows prefer mangers that offer the opportunity to eat in a natural grazing-like position compared with eating from elevated bunks (Albright, 1983). Also, behavioral activities contributing to feed wastage, such as rooting feed out of shallow, elevated bunks and feed tossing, are virtually eliminated. Preferred manger floor height is slightly above the floor on which the cow stands. Albright pointed out also that cows produced 17% more saliva, a natural buffer, when eating with their heads downward. Here is an example of a situation in which consideration to facility design can have a positive impact.

A post-and-rail feed manger is shown in Fig. 12-6. The position of the neck rail, offset away from the cow, allows the animal to reach further while exerting less force on the rail. Also, offsetting and raising this rail allows cows to stand closer to the manger wall, increasing the ability of cows to reach feed while reducing the possibility of injury. The feed surface may be elevated 2 to 6 inches above the cow alley in the fenceline manger. Minimizing this elevation maximizes the height of the manger wall against which the cows' ration is piled. This maximizes the amount of material that can be deposited in a given feeding.

Suggested dimensions for post-and-rail feeding mangers according to the design of Fig. 12-6 are given in Table 12-3 for dairy heifers and cows.

Recommendations for waterers, including location, size, height, and number, seem to have evolved over the course of time. Design guidelines at this time are to provide at least one watering space or 60 cm of tank perimeter for every 15 to 20 cows. At least two waterer locations are needed for each group of cows. Provide more space and more locations if 2-year-olds are housed with older cows. Limit water depth to 15 to 20 cm for fresher water and less debris accumulation.

Access to adequate fresh water becomes even more important in summer as consumption per cow increases. Extra water tanks in the barn should be considered for use during hot weather. In fact space should be designed for such tanks in new barns. Heaters will not be required, since these tanks will be removed for cold weather.

Walking Areas and Surfaces

Substantial competition occurs among cows as they used the space allocated to them in freestall barns (Potter and Broom, 1990). Areas used most intensively are the crossovers be-

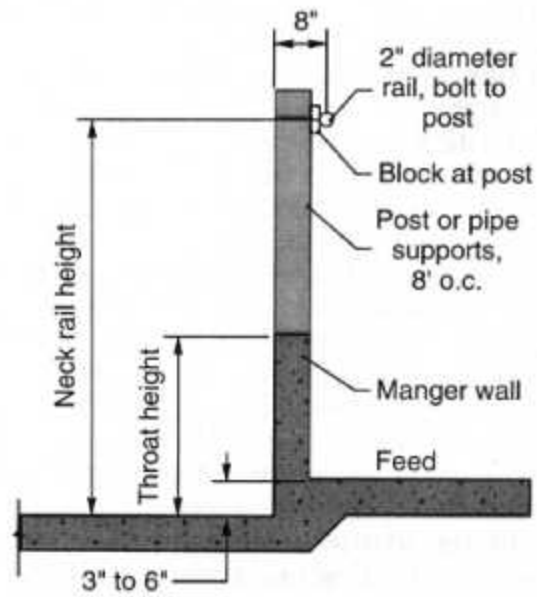

FIG. 12-6 Post-and-rail feeding fence. Refer to Table 12-3 for neck rail and throat heights.

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tween rows of freestalls, spaces around waterers and other prime sites within the barn such as feeding areas, holding areas, and entries and exits from the milking parlor. An underlying level of social aggression, promoted by social hierarchy of animals and the competitive use of space, can often produce sudden actions of avoidance, causing animals to slip and to fall on manure-covered surfaces. This can lead to damage to legs, followed by upper leg lameness.

The width of alleys between a feed bunk and an opposite wall should be 3.5 to 3.7 m. This allows two cows to pass each other while others are feeding. If, as in Fig. 12-7, a row of freestalls opens to the alley opposite the feed bunk, the width of the alley should be 3.9 to 4.3 m to allow for the additional activity of cows entering and leaving stalls. Oftentimes, waterers are located at the end of freestall rows in the crossover area. The width of the crossover should be at least 3.7 m plus the space occupied by the waterer.

When a cow is in the alley away from the feed manger (the alley along an outside wall in Fig. 12-7), the distance that she must walk to access a crossover, and thus the feed manger, is of interest to nutritionists. A rule of thumb is to limit the cow's walking distance to access a crossover to the equivalent of 15 to 20 freestall widths. Thus, if a cow is standing at the midpoint of the outside alley, she could walk 15 to 20 freestall widths either way. Therefore, the maximum number of freestalls in a row between crossovers is 40, or a maximum of 80 freestalls in a group of stalls head-to-head as shown in Fig. 12-7.

The drive-through feeding alley is for a feed truck or a tractor and trailer-mounted mixer. A minimum width of 5.5 m is recommended to avoid the possibility of driving over feed already deposited while making a return trip through the barn to deliver feed to the other side.

Skid-resistant walking surfaces reduce injuries; improve movement to feed, water, and resting areas; and enhance estrus detection. The walking surface for the cow must be sufficiently aggressive to prevent her from slipping or skidding as she walks but not so aggressive as to injure the underside of the foot. Thus choice of floor surface is a matter of compromise, as is all of design.

Dumelow and Albutt (1990) examined the design of the optimum slip-resistant concrete floor surface for dairy cattle using a mechanical foot simulator rig. This allowed for precise measurement of the spatial dynamic movement of the mechanical foot on different surfaces. They concluded that, for optimum slip-resistance, floors for dairy cattle should be wood-float finished and that they have parallel grooves 10 mm wide running perpendicular to the direction of walking. The grooves should be spaced at 40-mm intervals. In the general circulation areas a pattern of hexagons with 46-mm sides formed by 10-mm grooves improves the antislip properties of the concrete floor.

In practice, parallel grooves approximately 12 mm deep, 12 to 19 mm wide, and spaced 90 mm on center are sawed or formed in concrete surfaces. These grooves act to arrest a skid perpendicular to the groove, but they are not effective when the skid is in the same direction of the groove. In high traffic areas, grooves are formed in two directions, causing a diamond-shaped pattern.

TABLE 12-3

Suggested Dimensions for Post-and-Rail Feeding Fence

Age (mo)	Weight (kg)	Throat Height* (mm)	Neck Rail Height* (mm)
6-8†	165-225	355	710
9-12	225-295	405	760
13-15	295-355	430	865
16-24	355-545	480	1040
Cows	545-680	530	1220

*Consult manufacturer for manger wall dimensions when installing self-locking headlock stanchions.
†A diagonal feeding fence (250-mm spaces between diagonal bars) is recommended for this group.

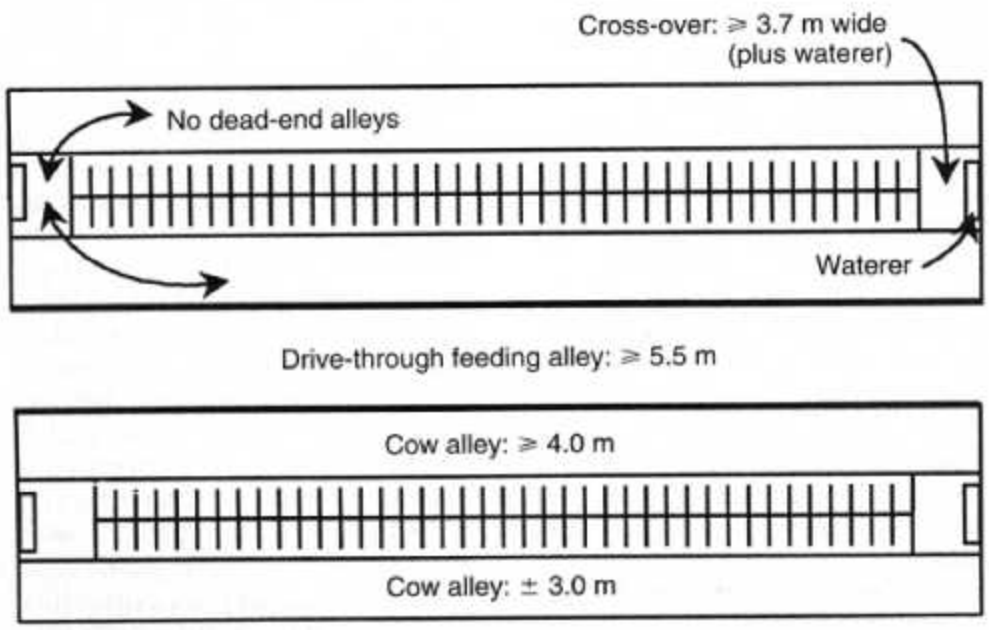

FIG. 12-7 Animal movement areas. The dimensions shown in this plan view of a four-row drive-through barn allow cows to have access to feed, water, and freestalls with a minimum of interference. The distance between crossovers should be limited to the equivalent of 40 stall widths, or 80 stalls in a module when two rows of freestalls are head-to-head.

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Concrete surfaces may have a texture that is too aggressive. Jagged edges, sharp points, and protruding aggregate that result from improper finishing and texturing all may be injurious to the sole of the claw. Impressing a texture into the concrete surface is preferred over dragging rakes or other tools across the surface in order to create roughness. During the impressing process, a lip may be formed at the edge of the impression because of displaced concrete. This lip traps liquid. Also, during forming, wet concrete may cling to the impression tool and be pulled upward, creating a feathered edge that protrudes above the alley surface and becomes very sharp as the concrete cures. This should be corrected by repeatedly dragging a heavy concrete block or a weighted steel-blade scraper over the concrete surface after the concrete is cured but before cows are introduced to the area. This procedure chips off sharp points, lessening their damaging effect. The alley surface should be swept clean after the sanding operation. Equally injurious is broken or highly eroded concrete that has a very rough and irregular surface. A qualified craftsman should repair such surfaces.

Frequent removal of manure (at least twice daily) greatly helps to enhance foot-floor grip and reduces exposure of the claw horn to manure and wetness. Prolonged contact between the claw horn and manure leads to softening of the claw wall and increases the rate of abrasion. This could lead to other forms of claw lameness.

HOUSING SYSTEMS

Factors Affecting Choice of Housing Type

Climate has had much to do with the type of housing used in certain areas and the developments that have taken place. In northern climates, barns were built to provide protection for the animals and the people keeping those animals against the long, cold winters. Pastures or other outside areas were likely used during milder times of the year. In areas where freezing temperatures and snow are not problems, shelter was less necessary. Year-round pasture systems may have provided the source of energy for the cattle, or corrals or dry lots where feed is brought to the animals may have been used.

The number of cattle on a farm has been another factor affecting type of housing, especially in colder climates. Stanchion and tie stall barns served well for herds ranging up to 50 or 60 milk cows. However, stall barns are labor intensive, both for milking and feeding. This has been and will continue to be an important reason for dairy farmers with larger herds to consider loose housing systems with milking parlors.

Changing economics has played a major role in determining the number of cattle on a particular farm, generally having a greater impact on dairy farms with fewer cows. Smaller dairy farms often experience higher costs and lower net returns than larger farms, a situation that worsens if costs of fixed assets-fixed investments on the dairy farm continue to rise in relation to the returns per cow. In some cases, revenues of the business may not be sufficient to support the capital investment and corresponding debt capital necessary to stay in business. For the farmer seeking profitability, one of the options available under these circumstances is to increase the size of the dairy herd. Fixed costs can be spread over more cows, and the farmer is in a better position to benefit from economies of scale. In countries with a milk marketing system based on supply control, the smaller dairy farm is at less of a disadvantage.

However, one of the most important reasons for changes in housing and equipment has been to keep abreast of the improvements in the genetic base of the animals on the typical dairy farm. With increasingly superior animals from the standpoint of their genetic potential for milk production, the more traditional facilities and methods become an obstacle to higher milk production. Existing facilities limit the ability to implement appropriate management recommendations. In addition, existing facilities may not meet the needs of animals from the standpoint of their environment, thus placing restrictions on productivity, health, and general welfare. Contemplating change is a dilemma for the dairy farmer (i.e., having to decide whether to make changes in an effort to maintain the status quo or to make no changes and fall behind). Meeting this challenge requires a careful examination of values, management style, and goals and development of a long-range plan for the dairy farm.

Housing for Milking Cows

Stall Barns

Early stanchion barns were typically two-story buildings with two rows of stanchions in a face-out arrangement and a few pens for calves and freshening cows on the first floor. The row on the second floor was devoted to hay storage. Sometimes the rows of stanchions were arranged in a face-in arrangement to facilitate feeding and the mechanization of feeding, but this arrangement compromised the milking operation. Engineers understood needs for insulation and ventilation, mechanical or gravity, but application of these principles often was lacking in actual practice. Some barns were equipped with mechanical gutter cleaners that eased manure removal and allowed a narrower center alley in face-out barns.

The typical northern stall barn of today is a well-insulated, single-story structure with mechanical ventilation. In some cases, natural ventilation has been used. Barn space is primarily for milking cows, with calves and other animals housed in other facilities. Comfort or tie stalls are more common than stanchions. Gutter cleaners are standard equipment, although a few stall barns have gravity-flow gutters. A trend to year-round housing and feeding in the barn has required more ventilation. In addition to continuous winter ventilation and thermostatically controlled spring and fall fans, fans are installed to provide summer ventilation on the order of 60 to 90 air changes per hour.

Freestall Barns

Freestall barns constructed today generally are based on using a mobile feeding system with a truck-mounted or trailer-mounted feed mixer equipped with electronic scales. Horizontal silos for corn silage, and possibly grass silage, and bulk storage for dry grains and supplement are compatible with this system. A tractor with a front-end loader loads feed components into the mobile scale-mixer. The scale-mixer itself is used to deliver the mixed rations to the cows. Groups of cows then can be fed differently according to their particular nutritional requirements. This has led to barn arrangements that permit division of milking herds into groups, usually by production.

Other grouping strategies and management practices may have positive effects on animal health (e.g., reducing incidence of lameness). Groups of older heifers housed in freestalls during the year before parturition, having already experienced use of stalls, will likely demonstrate a higher rate of freestall use as primiparous animals. As already discussed, freestall use has important implications with respect to lameness. Primaparous cows segregated in a group from multiparous cows are subject to less bullying by the older animals, reducing the possibility of animals falling. From a nutrition standpoint, high-producing cows will show a lower incidence of laminitis when grouped separately and fed a separate ration during the 2 to 3 prepartum weeks. Maintaining DMI during this critical time helps avoid numerous other health-related problems as well.

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Freestalls are used to some extent in combination with outside lots or corrals, particularly where periods of excessive rain make concrete in the housing and feeding area desirable. In the north, these open-lot systems, where feeding was done in an exposed concrete feed alley or lot and a feed bunk, are gradually being abandoned or converted in favor of a completely covered facility. In new construction, joining of the milking center to the freestall barn allows all animal traffic areas to be covered. This reduces problems arising from frozen manure and snow and the need for runoff control.

Corral Systems

In warmer areas where freezing temperature and snow are not problems, loose housing systems usually are based on outside corrals or lots. Freestalls are used to some extent, particularly where periods of excessive rain make concrete in the housing and feeding areas desirable. In most cases a dirt lot is provided as well.

Open dry-lot corral systems without freestalls remain popular where rain does not pose a problem during most of the year. These systems are based on dirt lots, sloped for drainage, with feed mangers along one end or a side. Drives are provided for mobile scale-mixers usually used for feeding. In some cases, evaporative coolers are incorporated into shade structures to reduce stress further during hot weather. Cow traffic patterns to and from the milking center are an important part of the overall design.

Dry Cow Housing

The early dry cow management category begins with a successful transition from a lactating state to a nonlactating (dry) state. Early dry cows are housed as one group for approximately 40 days. Early dry cows may be housed on pasture, on a bedded pack, in free stalls or in comfort stalls.

Approximately 2 to 3 weeks before expected calving date, dry cows and heifers should be moved to the precalving group. The precalving management program calls for more careful attention to nutrition and sanitation, since cows and heifers near, during, and after giving birth to offspring are at greater risk for infectious diseases and noninfectious disorders. Housing for precalving cows and heifers should allow for frequent observation and be convenient to the maternity area. Free stall housing is recommended to reduce exposure of the udder to mastitis-causing organisms. Restricting access to outside dirt lots reduces risk of mastitis also.

Just before calving time, cows and heifers should be moved to individual pens that are separate from other animals, especially younger calves. The location of this area and assignment of responsibilities to personnel should encourage frequent observation. Then the animal that has just calved should be observed frequently for problems before moving her to the milking herd. The newborn calf, having received about 2 to 4 L of high-quality colostrum, a dry haircoat, a disinfected naval, and other medical treatments, should be moved to a calf hutch or individual pen until weaning.

Calf and Heifer Housing

The calves and heifers on a dairy farm represent the future of the milking herd. Beginning at birth the replacement animals should be the best of the lot, genetically superior to the older animals. Accomplishing this is the result of a well-managed breeding program; taking advantage of the genetic superiority requires implementing a sound management program based on current recommendations.

From an environmental standpoint, raising healthy, potentially high-producing replacement animals requires housing that provides adequate space for water, feed, resting, and exercise. High humidity is especially detrimental to animal health requiring adequate ventilation to remove the moisture produced by the animals themselves. Adequate ventilation also removes other air pollutants so as to maintain suitable air quality.

Calf Housing

From birth to age of weaning (2 months), individual hutches, pens, or stalls should be provided. Cold, naturally ventilated housing is preferred. A calf hutch that is clean and dry with ample amounts of dry bedding has proved to be a desirable option. From an environmental view, the benefits of a hutch are:

- No contact between calves (reduces spread of disease)
- Well-ventilated area (air inside hutch is similar to outdoor air)
- Adequate space (dry bedding is easier to maintain)
- Ability to move to a clean spot (breaks a potential disease cycle)

The calf hutch is the gold standard for calf housing in terms of the environment it provides. Any decision to choose something other than hutches in the interest of working conditions for people or for equipment must be made in full view of the potential consequences. Thus, before making a decision to choose something other than hutches for housing calves, consider the attributes listed above. Whenever an attribute is lost, calf health is placed in greater jeopardy—the more attributes that are lost, the greater the jeopardy. For example, choosing group housing over individual housing places risk on calf health from the standpoint of spread of disease and competition. Moving calves to pens inside a building may compromise ventilation or the ability to provide a clean, fresh place for the newborn calf. Thus, as in all facilities' decisions, choice of calf housing is the result of a compromise and a process of making choices after carefully considering all of the consequences.

Transition Housing

An important management category is comprised of calves from weaning up to 5 or 6 months of age—the transition group. From an environmental standpoint, these calves have special needs that differ from older heifers. Small groups should be maintained. For a 100-cow dairy, four to six calves per group will sufficiently minimize the difference in size among calves in the group. Well-bedded pens should allow 2.3 to 2.8 sq m/calf—a 3.65 m × 3.65 m pen can hold up to five calves.

Transition housing for calves that have been raised in individual hutches or other cold housing can be provided with the following:

- Portable calf shelters or super hutches
- Group pens in an existing well-ventilated building
- A transition barn or a building constructed specifically for the transition stage

The environment should be similar to that in which the calves have already become acclimated with sufficient ventilation for moisture control and protection from the elements in winter. In cold weather a thick, dry, erect haircoat is essential to reduce heat loss from the calf and accompanying environmental stress.

Heifer Housing

In colder climates heifers are usually housed on a bedded pack or in free stalls, at least in winter. Pasture and other

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outside lot systems are used as well. Regardless of housing type, animals should be grouped according to a management plan. Variations in size and nutritional health and reproductive needs may then be accommodated.

SORTING, HANDLING, AND RESTRAINT FOR TREATMENT

Handling, restraint, and treatment facilities are essential to a successful dairy facility, permitting implementation of many management recommendations. As a rule, a sorting and restraint system should provide one person with the ability to perform the following:

- Observe calves, heifers, and cows
- Identify selected individuals for sorting or treatment purposes
- Separate selected animals from the rest of the group
- Move sorted animals to a treatment location
- Restrain animals for medical examination, treatments, and other procedures as needed.

Treatments and examinations include vaccinations, dehorning, weighing, artificial insemination, estrus synchronization, and pregnancy checking.

Each group of animals, organized for management purposes, must have provisions for sorting and restraint. Choice of method will vary with age or size and the particular housing facility. Provide feed and water for animals that may be restrained for treatment in an area away from regular sources. Provide the capability of lifting individual feet of animals to allow for inspection and treatment of the claw and associated areas. Do not examine or treat dairy animals in the milking parlor.

Three locations are available for sorting milking cows: the milking center, the freestall barn, and a separate facility. The milking center is a convenient place to sort cows as they exit from the milking parlor if cows travel single file. Two parallel lanes—one for returning cows to the housing area, the other for catching cows—are provided at the parlor exit. A power-operated cutting gate located in the return lane may be used to divert individual animals. If manually controlled, the cutting gate is situated near the rear of the parlor in an area easily viewed by the person milking. Moreover, if the parlor is to be idle for more than 2 hours between milkings, provisions for restraining cows for treatment may be included. Plans for using the holding area, the return lanes, and the area alongside the holding area for sorting, restraint, and treatment are available (Bickert and Stowell, 1997; Mid-West Plan Service, 2000).

More recently, automatic sorting systems based on cutting gates coupled with electronic identification of animals have come into use. Power-operated cutting gates programmed to operate in combination with an automatic cow identification system may be located (1) in a return lane near the rear of the parlor, (2) at the extreme end of a return lane, or (3) beyond the return lane.

Ganglock stanchions along a feed manger can restrain animals for various purposes. This is common on dairies where milking parlors are operated most of a 24-hour day and sorting capability is not part of the milking center. Each ganglock stanchion is equipped with a self-locking feature that is actuated when the cow puts her head in a stanchion and reaches for feed. Stanchions designed to allow individual release of animals might be used for sorting purposes as well. Whether associated with a freestall barn or with open lot housing, ganglock stanchions along the feed manger are used similarly.

For large herds a separate handling and treatment facility may be desirable. On some farms this facility may be the sorting site and may provide restraint for treatment and other purposes. In other words, all such work is done here. Usually, animals needing treatment would be sorted elsewhere first and would then be brought to this separate facility as individual animals or groups of sorted animals. For example, animals could be sorted as they leave the milking center. Sorted animals could be held in the catch lane (or diverted to a pen or other holding area) and then moved to the separate treatment facility.

The separate facility should be equipped with enough pens to accommodate the number of different sorted groups expected to accumulate during the course of a milking shift plus any groups that might be held for longer periods. Smaller pens for individual cows could be equipped with individual stanchions; larger pens could be equipped with a section of ganglock stanchions. Pens may be bedded and freestalls may be provided for larger groups. A chute and headgate system(s) as well as a tilt table or a stand-up hoof-trimming chute might be included in the facility. Feed and water should be provided for animals to be held more than a few hours.

A loading chute with solid sides for receiving and shipping animals is highly desirable. The ability to quarantine animals coming to the farm is also desirable. Practitioners should provide a holding pen to hold animals before loading and provide adequate consideration to safety in all cases: safety of persons handling, examining, and treating animals and safety of the animals themselves.

MANURE MANAGEMENT

Manure management is one of the major issues facing animal agriculture. The traditional view of a manure system—production, collection, storage, transport, and land application—has led to manure system designs that meet the needs of the dairy farm as well as satisfying the interests of the rest of society. But future planning must go beyond the traditional view. Manure management is a complex issue and is different from other farm management problems. Manure management decisions are closely intertwined with decisions about many different aspects of the dairy production system, including the buildings and other equipment selected for managing the herd and the cropping program.

Unique Aspects of Manure Management

Manure management is different from most other farm management problems. Also, many of the problems related to manure are of a different type, more social in nature than experts in the physical sciences are accustomed to addressing. The following are some examples of differences:

- Solutions to manure management problems require knowledge from several different subject matter areas. Manure management is not a discipline in itself, thus it is not identified with a specific discipline. Manure management is made up of bits of knowledge from several subject matter areas (engineering, microbiology, chemistry, agronomy, economics, and even the social sciences). Integrating inputs from these several subject matter areas is essential to addressing the problems faced by the livestock producer and the rest of society. But this integrator has generally been lacking.
- The issue involves a wide variety of agencies—local, state, federal—as well as wide variety of individuals. They may have very different perspectives on manure. Their reasons for being interested and becoming involved in the manure management issue vary widely. In addition, some of these agencies do not have a long history of working with one another.
- Manure management has the attention of several segments of society—besides dairy, livestock, and poultry

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farmers—and all of this attention is not necessarily an asset. This is particularly true in areas where animal agriculture is well established and wishes to coexist in harmony with other segments of society, some already there, some new to the area. Informing the general public about the positive actions regarding manure management that are already occurring on dairy farms is essential. This applies also to food safety and animal welfare, two other topics attracting the attention of the rest of society. Informing the general public can, of course, be accomplished more easily and more effectively if done through an organized approach.

Traditional View of Manure System Design

The traditional view of manure system planning centers on viewing the system as components of collection, transfer, storage, possible treatment, and nutrient utilization. Good design ensures that all components of the manure system will operate together to economically and effectively manage the manure until it reaches its final destination, typically being applied to the land.

Collection

In freestall barns, manure collects in the barn alleys and must be removed. Conventional or skid-steer—type tractors equipped with a bucket loader, steel blade, or rubber-tire scraper are common, especially in cold climate areas. Manure is removed from the animal area, perhaps each time a group of cows is away at the milking parlor. In warmer climates and in some barns in colder climates, manure is removed from concrete cow alleys by flushing with large volumes of water. Another alternative is a mechanical alley scraper, a device that is pulled along the alley by cable or chain and moves manure to the end of the alley.

Transfer

Methods of transferring manure to storage include scraping, pumping, and gravity flow. Often, manure is moved directly to storage by the tractor scraper. This is especially true when sand bedding is used in the freestalls. To reduce wear on equipment and problems with clogging of pipes with settled sand, a storage for sand-laden manure is usually located very close to the barn so that the storage can be loaded through a push-off wall along the side of the storage. Moving the manure from the alleys to an intermediate pit from which it is pumped to storage is another option. If topography allows, gravity flow pipes can be used to transfer manure to storage using the hydraulic head exerted by the more-or-less liquid manure. The latter two options do not work well with sand.

Storage

Manure is stored in earthen storage basins and below- and above-ground tanks. Typically, 10- to 12-month storage capacity is recommended and may include all animal manure, milking center effluent, and polluted runoff. Manure from freestall barns bedded with organic material, diluted with milking center effluent, and rainfall on the storage, can usually be agitated and pumped. In some cases, especially with sand-laden manure, a storage with a concrete bottom that can be entered with a tractor is required to completely empty the storage.

Possible Treatment

Treatment options for dairy manure include composting, anaerobic digestion, and, for sand-laden manure, sand separation. Composting requires that large masses of bulking material be added to the manure for purposes of reducing moisture content, adding carbon and enhancing aeration. The final mixture, positioned in windrows or piles, requires frequent stirring for aeration purposes. The benefits of composting are a stable end product, reduced odor, and reduced volume.

Methane, a product of anaerobic digestion, has been used to generate electricity. The complexity of the systems and components and the questionable economic return have limited application of this alternative.

Sand-manure separation significantly reduces the amount of sand entering a manure storage, thus reducing settling and handling problems. Furthermore, the reclaimed sand may be reused for bedding.

Nutrient Utilization

Spreading manure on the land has been the traditional method of disposing of manure. Ideally, the manure nutrients are considered in the cropping program, especially to offset the use of commercial fertilizers. Because excess nutrients are primarily why manure is an environmental concern, animal scientists are now examining ration formulation, realizing that a high percentage of the various nutrients fed to animals are excreted in the manure. Lowering the percentages of nutrients passed in the manure not only reduces feed costs but reduces pollution potential as well. Moreover, the land area required for spreading may be less if manure nutrients are reduced.

High-Priority Decisions in Manure System Design

Decisions about manure system design are among the most complex decisions on the dairy farm. This is not because equipment choices for manure collection and transport, or the types of manure storage available, or the methods of land applying manure are so complicated. Rather, the complexity arises because of the impact that the manure system has on numerous other aspects of the buildings and equipment on the dairy farm. The buildings and equipment on the dairy farm enhance the ability to manage animals. As well, they aid in providing a quality environment for the animals. Thus decisions about the manure system are related to the requirements of a well-thought-out management program and a clear description of the environment to be provided for every animal on the farm.

Ultimate Fate of the Manure

If manure is to be applied to the land to meet agronomic needs, the land must be deficient in those nutrients contained in the manure that are needed for the crop. Not applying nutrients in excess of a crop's needs is in the interest of both good nutrient management and responsible environmental management. Thus land may become a limiting factor when considering expansion or construction of a new dairy.

If land is limited, options include arrangements with nearby crop farmers to utilize the manure and purchase of additional land to receive the manure. If the land available is not immediately adjacent to the dairy, manure transport or remote storage may be considered. Large over-the-road tankers are being used to haul manure to remote locations where the tanker itself is used for spreading or the tanker is used to supply smaller field spreaders. Manure may also be transported to a remote storage.

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Pumps may be used to move manure up to several miles to a remote storage or to apply the manure directly to the land. Irrigation is a lower-cost method of applying manure to the land and may be an appealing way to spread manure. The water contained in the manure will likely supply only a small percentage of the total crop need. Other sources of irrigation water (e.g., a well) must be available to supply the remainder. There are other considerations in the decision to irrigate. The odor created while irrigating can be substantial, possibly affecting neighbors. If sand is used for freestall bedding, special consideration must be given to removing this sand to minimize impact on pumping and irrigation equipment.

In all cases, maintaining a low profile is advised—reducing visual awareness, reducing objectionable odors, and avoiding runoff. With irrigation systems this may mean changing to low trajectory equipment. Other options include tank spreaders equipped with deep or shallow injectors, or an umbilical hose pulled across the field may supply injectors on the tool bar of the tractor. Low trajectory boom attachments and dribble bars are alternatives.

Choice of Freestall Base and Bedding

Choice of bedding is a critical decision. Choice of bedding should reflect management style and goals, especially with respect to level of milk production and SCC. At the same time, choice of bedding has a profound impact on manure system design.

Two methods for satisfying the requirements for freestall beds that promote cow comfort and good udder health are 6 to 8 inches of loose sand and rubber-filled mattresses with organic bedding on top. Although mattresses, properly installed and maintained, can contribute to a desirable environment for the dairy cow, sand appears to have the advantage. In fact, the only logical reason for not using sand has little to do with cow comfort and udder health. It has to do with the difficulty it adds to the manure system or the availability of high quality sand. This may lead to a decision to (1) use sand despite the difficulties, (2) use sand but seek ways to reduce its impact on the manure system, or (3) use mattresses and organic bedding and avoid the problems with sand altogether.

In spite of the difficulty, many dairy farmers have chosen sand for freestall bedding and are using a variety of handling and storage methods (Stowell and Bickert, 1995). Simply put, the final decision is whether to favor cow comfort and udder health or manure handling and storage.

Method of Applying Manure to the Land

Another decision that must be made early in the process is choice of method of applying the manure to the land and whether the manure will be handled as a semi-solid or a liquid. The majority of dairy manure is stored, handled, and applied to the land in liquid form. But, in fact, liquid manure handling is more energy intensive, and the equipment is more expensive than if the manure were to be handled as semi-solid. But the trend toward liquid manure has continued because it is the most timely alternative and generally involves less labor.

The actual method selected for applying manure to the land depends on many factors. If manure is broadcast, losses of nitrogen from volatilization of ammonia can be high and odors may be more objectionable to neighbors. Incorporation by plowing or disking is advisable. Injection of manure, either deep or shallow, reduces potential odors, runoff, and nitrogen loss as well.

Allowing bedding sand to remain with the manure greatly complicates, if not eliminates, the possibility of handling manure as a liquid. At the very least the sand in the manure is very abrasive to the equipment that has been developed for liquid manure.

HEALTH PROBLEMS RELATED TO ENVIRONMENTAL MANAGEMENT

In addition to diseases of the respiratory tract of housed dairy cattle (especially calves) that are associated with housing and environmental factors, lameness occurs commonly in confined mature dairy cattle. The trend of the last 25 years to confine high-producing dairy cows on concrete floors has been associated with an increased prevalence of diseases of the feet, causing lameness that is considered to be the third most economically important disease after reproductive failure and mastitis. The epidemiological aspects of lameness and other diseases associated with housing, including parasitism and behavioural abnormalities, are described here. For the clinical details of lameness in cattle and descriptions of the various lesions causing lameness in dairy cattle, the reader is referred to other textbooks (Greenough, 1997) and documents (Bergsten, 1995).

Lameness in Dairy Cattle

Prevalence, Incidence, and Economic Losses

Lameness in dairy cattle is a major cause of financial loss and inconvenience to dairy farmers and of pain and discomfort to cows. Next to mastitis and reproductive failure, lameness is an important cause of involuntary culling in dairy herds. Approximately 90% of cases of lameness in dairy cattle are caused by lesions of the feet and 10% by lesions elsewhere on the limbs. The proportion of cows culled for locomotor disease may be as low as 2.7% in studies in France (Seegers et al, 1998) and up to 5.6% in England (Esslemont and Kossaibati, 1997). Lameness, mastitis, and teat injuries collectively may have a large effect on culling in some dairy herds (Rajala-Schultz and Gröhn, 1999). In a study of culling of Holstein herds in Quebec, over a period of 16 years for 1.5 million lactation records, involuntary culling increased from 23% to 32%, as opposed to voluntary culling for low milk production, which decreased from 16% to 4.5%. The increase in involuntary culling was mainly due to increased trends in culling for reproductive problems, mastitis, and feet and leg problems (Durr et al, 1997).

The reported frequency of lameness, based on 39 citations in the literature from 1972 to 1995, ranged from a lactational incidence of 1.8% to a mean annual incidence rate of 30% (Kelton et al, 1998). The median lactational incidence rate was 7.0%. A cow is considered to be clinically lame if she had an episode of abnormal gait attributable to either the foot or limb, regardless of etiology or duration. A case is considered new if the cow has not been clinically lame in that limb during the preceding 30 days. A case is considered as a first occurrence if it was the first recorded case of lameness for a cow in the current lactation. A lactational incidence rate, expressed as affected lactations per 100 lactations at risk, is reported as follows: (number of lactations with one or more lameness events / number of lactations) × 100. A cow is included in the numerator only once per lactation. A true incidence rate, expressed as cases per 100 cow-days at risk, is reported as follows: all cases, (number of cases of lameness during the time period [TP] / number of cow-days at risk during the TP) × 100; first cases, (number of first cases of lameness during the TP / number of cow-days at risk during the TP) × 100.

The prevalence and severity of lameness in lactating dairy cows in a sample of Minnesota and Wisconsin dairy herds found the prevalence of clinical lameness was 13.7% in

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summer and 16.7% in spring (Wells et al, 1993a). These prevalence rates were 2.5 times higher than those estimated by the herd managers. A higher prevalence of lameness occurred in cows of higher parity. In a survey of 185 dairy herds consisting of 21,000 cows, the average incidence of treatments for lameness was 25% (Whitaker et al, 1983). An annual incidence of up to 60% has been suggested if all treatments given by the farmer and the veterinarian are included (Eddy and Scott, 1980). Approximately, 7% of Danish dairy cows receive veterinary treatment for lameness during a lactation (Alban, 1995). In Denmark the cow's incidence risk of foul-in-the-foot was 0.6% during the first month postpartum (Alban et al, 1995). This was six times higher than in the last month prepartum and in any other month postpartum. Almost half of the first treatments for foul-in-the-foot were provided within the first 30 days after calving.

In a survey of 90 Holstein dairy herds in England (average size of 152 cows) over a 12-month period, 17.4% of the cows were affected with lameness, with 1.4 cases/affected cow and a total of 24 cases/100 cows (Esslemont and Kossaibati, 1996). It is suggested that the increased incidence of lameness in dairy cattle in the last 30 years is associated with the introduction of cubicles compared with 3 decades ago when cows kept mainly in straw yards.

In a survey of 37 dairy farms in England over a 30-month period, the incidence and prevalence of lameness in the cows was obtained from records made whenever a cow was examined for lameness or her feet were trimmed prophylactically. The mean annual incidence of lameness was 54.6 new cases/100 cows with a range from 10.7 to 170.1, and the mean values during the summer and winter were 22.9 and 31.7, respectively (Clarkson et al, 1996). The prevalence of lameness was measured by regular visits at which locomotion was scored on a scale of 1 to 5, and the prevalence of lameness was calculated for each visit as the proportion of cows with scores of 3 or more. The mean annual prevalence over the whole period was 20.6% with a range of 2.0 to 53.9% for the 37 farms. *There was evidence that educating farmers to recognize early cases of lameness and requesting veterinary care caused a marked reduction in the duration of cases of lameness.*

Lameness in dairy cows is both a welfare problem and a source of economic loss to the dairy herd and the industry (Logue, 1995, 1998). In the United Kingdom, annual losses caused by lameness have been estimated to be about £90 million annually (Bennett et al, 1999). Lameness may affect the producer in several ways: *increased labor requirement, increased treatment costs, reduced milk production, reduced fertility and involuntary culling, and decreased slaughter value.* The economical loss is difficult to evaluate, but the average cost of sole ulcer in dairy cows has been estimated to be £227 to £297 (Esslemont, 1990). The direct cost of a sole ulcer is estimated at £72. However, the cost associated with reduced fertility is far more expensive, estimated at about £246 assuming that the affected cow will have a calving interval extended by 22 days, with a need for an extra 0.7 services per conception and an 18% increase in the risk of culling (Kossaibati et al, 1997). On a cow basis, the average dairy herd is losing £27 per cow per year when compared with the average performance of the top quarter of herds, whereas the potential losses are £55 per cow for a herd within the worst affected quartile (Kossaibati et al, 1997). In dairy herds in England, it is estimated that the main economic losses are due to mastitis and lameness at 38% and 27% of the total health cost, respectively (Kossaibati and Esslemont, 1997). In the Netherlands lameness in dairy cattle accounts for an estimated loss of 4% to 5% of a typical dairy farm income (Enting et al, 1997). Digital disease in dairy cattle in Quebec has been estimated to cost $10 million (Can.) annually (Choquette-Levy et al, 1985).

Lameness is also associated with reduced milk production. A lame cow, if left untreated, may decline in body condition because of its inability to feed normally. A review of the published literature on the effects of disease on milk production found that across the lactation, loss estimates averaged 80 to 350 kg of milk (Fourichon et al, 1999). The effects of foot lesions on milk production are most pronounced in mid- to late-lactation stages (Boulon et al, 1996). In studies in the United Kingdom, cows lame during the summer months lie down for longer than normal periods and spent less time eating (Hassall et al, 1993). Cows also grazed more slowly as measured by the bite rate. Affected cows lose weight, come into milking parlour later, and may be more restless when being milked. During the winter months, lame cows lie down for longer periods in the cubicles (Singh et al, 1993a). They may also stand or lie in unusual postures in an attempt to alleviate discomfort.

Lameness may also reduce the expression of estrus, thus affecting reproductive performance, which increases the risk of early culling. Lameness can prolong the interval from calving to first service and the interval from first service to conception (Barkema et al, 1994). Dairy cows with a lameness score greater than 2, based on a 5-point lameness scoring system, may have an extended interval from calving to first service and to conception, spend more days in the breeding herd, require more services per pregnancy, and be 8.4 times more likely to be culled (Sprecher et al, 1997).

Frequency of Lesions that Cause Lameness in Dairy Cattle

There has been a notable lack of basic and applied research on lameness in cattle. Consequently, there is insufficient reliable literature on the subject. One major problem has been the lack of a consistent nomenclature with which to describe the several different lesions of the feet of cattle. There is now international agreement on the nomenclature of the diseases of the ruminant digit, which should improve communications and understanding of the literature on the subject (Weaver et al, 1981).

The most common causes of lameness in dairy cattle are due to diseases of the claws. In a survey of 37 dairy farms, in four regions in England and Wales, data on 8991 lesions and the preventive trimming of 4837 cows' feet were tabulated (Murray et al, 1996). Lesions in the hindfeet accounted for 92% of lameness, of which 65% were in the outer claw, 20% in the skin, and 14% in the inner claw. Sole ulcers (40%) and white line disease (29%) were the predominant diseases of the horn, and digital dermatitis (40%) was the most common disease of the skin. The laminitis-related diseases of the claw (sole ulcers and white line disease) account for about 70% of the lesions, and digital dermatitis accounts for about 30% of the acute lameness. Similar frequencies of claw lesions have been found in dairy herds in the United States (Bergsten et al, 1998). In a survey of lameness in dairy herds in Israel, the most prevalent lesions were solar hemorrhages averaging 28.6% and white line separation at 26.7% (Bargai and Levin, 1993a,b). These two lesions are considered to be sequelae to subclinical laminitis.

Diseases of the Feet

Lesions of the Sole and Bulb Horn. Sole and bulb lesions are the most common causes of lameness.

Sole hemorrhages of different sizes and severity appear in the surface of the sole as the result of lesions originating in the corium. At the normal rate of growth of the horn, two to three months are required before the hemorrhages become visible at the surface of the sole. The hemorrhages are

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considered to be retrospective evidence of laminitis. Slight hemorrhages usually regress spontaneously. More severe hemorrhages in the corium develop into a double sole, sole ulcer, white line disease, or underruning of the heel.

Sole ulcer is a circumscribed defect of the sole horn continuous with the corium.

White line disease is a lesion of the lamellar horn of the sole, most often in the posterior abaxial wall. It is thought to be derived from a hemorrhage in the laminar corium and is often observed with other hemorrhages in other parts of the surface of the sole. The site of the lesion adjacent to the wall makes the wall less resistant to torsion, abrasion, and load bearing. Thus the incidence of white line disease is higher in animals kept on abrasive floors and in grazing animals that have to walk long distances.

Claw abscess is a local, septic inflammation of the sole corium. It may develop from a secondarily infected double sole, from a sole ulcer, from underrunning of the heel, or from a white line or wall lesion. It may also be due to a traumatic lesion of the sole caused either by a foreign body or by trimming the foot too deeply or by excessive wear.

Heel erosion is a disease characterized by erosion of the heel horn. It may be caused by bacterial infection or physical or chemical agents eroding the heel. Lameness is usually minimal. It is also called *chronic foot rot, underrunning of the sole-heel junction, slurry heel,* or *contagious interdigital dermatitis.*

Lesions of the Digital and Interdigital Epidermis. Most of the diseases of the skin of the bovine digit associated with lameness are infectious, and most are due to bacterial species specific to the digits (Demirkan et al, 2000). Infectious diseases of the skin of the digits of dairy cattle are usually associated with muddy corrals and alleyways.

Digital dermatitis (also termed *Mortellaro disease, papillomatous digital dermatitis* or *hairy warts*) was first described in Italy and occurs in dairy herds throughout the United Kingdom, Europe, Asia, Africa, Australia, and North America (Demirkan et al, 1999). It has now become one of the most common causes of lameness in dairy cows. The lesions are characterized by a diffuse or circumscribed inflammation of the skin at the coronary margin, commonly occurring at the plantar aspect of the interdigital space just above the cleft and midway between the heel bulbs. Initially there is severe lameness, forcing the cow to walk on its toes. The disease responds well to topical administration of antibiotics. The precise etiology is uncertain, but spirochetes have been found in lesions, and serological evidence of infection with *Borrelia burgdorferi* has been found (Demirkan et al, 1999).

Foul-in-the-foot or *interdigital necrobacillosis (footrot)* is caused by *Fusobacterium necrophorum* usually following injury to the interdigital skin. The characteristic clinical findings are acute lameness, swelling of the coronary band forcing the two claws apart, and a crack in the interdigital skin that exudes a foul-smelling exudate.

Interdigital dermatitis (Dermatitis interdigitalis) is a superficial inflammation of the interdigital skin, most commonly in the plantar commissure (Bergsten, 1995). The disease is most common in poor hygienic conditions in intensively managed dairy herds. The hindfeet are most commonly affected. *Dichelobacter (Bacteroides) nodosus* has been isolated from affected cows. The lesion does not generally cause clinical disease and can be prevented by adequate hygienic measures, the use of local antiseptics, and foot bathing.

Verrucose dermatitis is a chronic proliferative inflammation of the dorsal and/or plantar aspects of the skin in the interdigital space, nearly always occurring in the hindfeet of housed cattle. The lesion appears as a cauliflower-like hyperplasia with a serous, oozing discharge just above the heel bulbs. Only individual cows are affected, and it is rarely a herd problem.

Interdigital hyperplasia is a proliferative reaction of the interdigital skin or subcutaneous tissue localized in the dorsal aspect of the interdigital skin but may extend to the palmar-plantar area. The mass of tissue is continuous with normal interdigital tissue, covered by hairless, thickened integument characteristic of this site. The hyperplastic tissue consists of fibrous connective tissue, some fat and is comparatively avascular. The cause is uncertain. There may be an inherited risk factor. Cattle with a narrow interdigital cleft are more prone to the lesion than in those animals with normal claws. It has been suggested that dirt becomes trapped between the claws, causing interdigital skin irritation and stimulating skin proliferation. Incorrect claw trimming, poor claw conformation, and slippery floors have been identified as potential risk factors. In older animals it may be a sequel to other lesions of the skin of the feet. Surgical correction is necessary.

Pathogenesis of Foot Lesions of Dairy Cattle

The pathogenesis of foot lesions of dairy cattle has been controversial. It is commonly said that lameness in dairy cattle is a multifactorial disease complex. There are some hypotheses. Lesions may result from direct trauma to the feet or from a combination of predisposing factors that have a nutritional or environmental and behavioral basis. Longitudinal studies of lameness in dairy cattle have found that many of the different kinds of lameness interrelate from one lactation to the next (Alban et al, 1996). Foot lesions of dairy cattle may be clinical causing lameness or subclinical with sole lesions only recognizable at trimming. They are thought to be the end result of interactions between multiple risk factors related to the cow or the environment, including factors related to both the housing system (type of floor) and management routines such as feeding and moving cows from the pasture to the milking parlor. Some of the commonly described factors are described here.

Nutritional or Metabolic Factors. A varying degree of laminitis is hypothesized to be the underlying lesion that causes metabolic or noninfectious lesions of the feet, such as sole ulcer, white line disease, heel erosion, and interdigital growths (Greenough and Vermunt, 1991; Enevoldsen et al, 1991a,b). It has been proposed that diffuse, acute, subacute or chronic laminitis precedes these lesions. A primary vascular change in the laminae causes edema and hemorrhage, stagnant hypoxia, and an inadequate supply of nutrients to the keratin-producing cells. Initially, there is toxic damage to the capillary walls. The final result is poor horn quality, followed by deterioration of horn (Bergsten, 1994). The inciting cause is hypothesized to be ruminal acidosis as a result of abnormal rumen fermentation associated with feeding a diet with high level of concentrate and a low level of roughage. The results of some feeding trials have supported the hypothesis, but the results have been controversial and in other feeding trials no effect of diet on the incidence of laminitis was found. In earlier feeding trials the incidence of solar lesions was higher in dairy cattle fed a high-level concentrate and low-level fiber diet than in cows fed a higher level of fiber. Also, the incidence of solar lesions was higher in cows fed a high-level protein diet in early lactation compared with a low-level protein diet. It has been hypothesized that the high protein diet causes an allergenic-histaminic reaction, leading to thrombosis of the laminae and laminitis. However, the hypothesis has not substantiated.

The literature on the predisposing factors of laminitis in cattle has been reviewed (Vermunt and Greenough, 1994). The cause of the disease is not well understood and is considered to have a multifactorial etiology. Considerable evidence suggests that laminitis can be a precursor of

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the common lesions of the sole and white line, which cause lameness in dairy cattle (Logue, 1995). Lesions of subclinical laminitis can be found in dairy calves 6 to 7 months of age raised outdoors (Vermunt and Greenough, 1995). Sole hemorrhages may be present in 77% of dairy heifers from 13 months of age to 2 months after calving—managed either indoors or in dry lots—and permanent injury to the claws may have already occurred before they reach maturity (Vermunt and Greenough, 1996).

The prevalence of lesions associated with subclinical laminitis in first-lactation cows from herds with high milk production is high, but there is a marked difference in the prevalence among herds. This suggests causative factors may vary among herds (Smilie et al, 1996, 1999).

In at least one study, sudden changes in nutrition, lack of transition in increased protein and carbohydrate levels in the ration, any increase in energy above 17.5 Mcal/kg of feed or in protein above 18%, sudden introduction of orange peels, and others have been associated as nutritional factors associated with subclinical laminitis (Bargai, 1998).

The source of dietary protein to dairy cows from week 3 to week 27 of lactation has no effect on locomotion, lameness, lesion formation, or any other hoof measurement (Offer et al, 1997). Cows were fed either a proprietary protein supplement of animal origin or soybean meal as the protein source in the concentrate. Sole hemorrhages, indicative of subclinical laminitis, were observed throughout the experiment but were most severe at approximately 16 weeks after calving. Levels of heel erosion remained constant. There was no significant effect of treatment on either heel or sole lesion formation.

The influence of diet before and after calving on feed intake, and on production and health of first-calf heifers, with special reference to sole hemorrhages has been examined experimentally (Olsson et al, 1998). Feeding high or low levels of concentrate during the last 2 to 3 weeks before calving had no effect on feed intake after calving; on milk yield, health and fertility; or on scores for udder edema and sole hemorrhages.

If some of these pathogenetic mechanisms are valid, the nutritional factors or practices that predispose to abnormal rumen fermentation need to be explored to determine if they can be prevented or minimized without sacrificing production.

Environmental and Behavioral Factors. Lameness in dairy cattle resulting from lesions of the feet has commonly been associated with environmental factors. The disease is most common in confined dairy cows compared with the lower incidence in cows kept on pasture. Many field observations have suggested an association between the incidence of lameness in mature cows and the quality of the indoor and outdoor walking surfaces. This includes the alleys or paths (cow tracks) that the cows use to walk from the pasture or housing to the milking parlor. Confinement of dairy cows on concrete floors is thought to contribute to the development of lesions of the claw horn and sole. Cows housed in poorly designed cubicles (free stalls) may refuse to lie down in them or lie down for only short periods This increases the total amount of time spent standing on concrete floors, which are unyielding compared with straw-covered wooden stalls of the past. Concrete floors may become eroded with concrete aggregate being exposed, which causes bruising of the soles. New concrete may be injurious because of the excess surface alkali. Slatted floors may cause lameness if the slats are fitted incorrectly or poorly maintained.

Lesions of the feet of dairy cows, such as white line disease, sole penetration, and bruising of the sole have often been associated with cow tracks, which are stony, rutted, and generally unsuitable for cows.

Constant wetness of the feet, as in cows forced to stand in slurry for long periods, probably contributes to infectious diseases of the feet, such as footrot and verrucose dermatitis (Williams et al, 1986). Constant wetting of the interdigital skin allows for propagation of the bacteria responsible for footrot.

Case-control studies in New Zealand have indicated that any management factor causing congestion or crowding of cows in the pathways to and from pasture can increase the incidence of traumatic lesions of the feet. The most influential variables in explaining variation between case and control herds were the average level of maintenance of the path and the degree of patience shown by the farmer in bringing in the cows for milking (Chesterton et al, 1989).

Traumatic flexor tendon injuries in cattle are commonly caused by accidents involving farm machinery (Anderson et al, 1996).

Risk Factors Contributing to Lameness in Dairy Cattle

Most cases of lameness in dairy cattle are due to lesions of the feet; the risk factors associated with lesions of the feet are complex, interrelated, and not well understood. Lameness in dairy cattle may be associated with herd-level or individual-cow-level risk factors. Herd-level factors include nutrition, housing, and flooring, and general management including frequency and adequacy of foot trimming. These variables contribute to differences in lameness among herds of dairy cows. Individual-cow factors include age, stage of lactation, breed, and season of the year. Other potential factors include body weight, body condition score, claw angle, and presence of limb lesions.

Herd-Level Risk Factors. There is a large variation in prevalence of lameness between herds. In some herds, severe claw disorders may be present whereas in other herds almost none may occur. The management routine for each herd is unique, which may account for the herd effect (Vaarst et al, 1998). Some of the herd-level risk factors can be considered.

Farmer's Knowledge Of Lameness. The attitudes and practices of dairy farmers can have a profound effect on the health and productivity of the herd. In a survey of 15 dairy farms in England, the prevalence of lameness was highly correlated and inversely with the knowledge, level of training, and awareness of the producers (Mill and Ward. 1994). Veterinarians evaluated the prevalence of lameness over a period of 8 weeks, and the farmer's knowledge of cattle lameness was assessed during that period. Factors evaluated included significance of lameness; economic importance; perception of risk factors; recognition of lameness; attitude toward treatment of lameness; prevention of lameness; and relationship between cubicle design, comfort, and lameness. The level of knowledge of lameness was low on farms with a high prevalence lameness; conversely, the prevalence of lameness was lowest on the farms in which the farmer had a high level of knowledge of lameness. This indicates a need for the promotion of educational programs designed to improve the farmer's level of knowledge about lameness.

Ratio of Concentrate to Fiber in the Ration. Feeding excessive quantities of energy relative to the requirements for milk production during the first several weeks of lactation has been associated with an increased incidence of lameness and foot lesions and with varying degrees of laminitis (Manson and Leaver, 1989). In one study of 30 first-lactation cows on a dietary energy intake 10% to 40% above recommended levels, 17 developed chronic laminitis with falling milk yield (Moser and Divers, 1987). However, a cause-and-effect relationship between diet and lameness in dairy cattle has not been substantiated.

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Cow Comfort and Quality of Indoor and Outdoor Walking Surfaces. Field observations suggest that abrasive concrete floors, particularly new concrete in new barns, some slatted concrete floors, and "rough" floor surfaces, contribute to traumatic injuries of the soles of dairy cattle (Rowlands et al, 1983).

Case-control studies of dairy herds under loose-housing systems and cubicles (free stalls)—with a high incidence of lameness caused by laminitis, leading to sole ulceration in replacement first-lactation heifers—found that in the problem herds, the heifers and cows *stood for significantly longer periods* than did herds with a lower incidence. A greater percentage of the heifers did not use the cubicles. The main difference between the management of the two herds was the amount of straw being used: one bale per 45 cows daily in the problem herds and one bale per 10 cows daily in herds with a lower incidence of lameness. In cubicles with deep straw, cows were lying down 14 hr/day, whereas in concrete beds with no bedding, cows were lying down for only 7 hr/day.

Laminitis has occurred in dairy heifers that calved in the autumn and that were housed in stalls with concrete floors and fed a high concentrate diet (Bergsten and Frank, 1996a,b). The risk of developing laminitis is high during the periparturient period, and the type of floor appears to be more important than the level of concentrate fed.

The influence of the cleanliness of the stalls of cows on the cleanliness of animals and their hooves, and the effect of cow trainers on the health of hooves, has been examined (Bergsten and Pettersson, 1992). Electric cow trainers reduce the prevalence of heel-erosion in housed dairy cows, and the reduction is related to the cleaner condition of the stalls and the improved condition of the hooves of the cows as a result of the cleaner conditions. Heel erosions are reduced in association with the introduction of a footbath (Bergsten and Herlin, 1996). Heel erosions are absent or rare in the fore hooves of both primiparous and multiparous cows in tie stalls (Bergsten and Herlin, 1996). Cows in cubicles have higher heel horn erosions in their fore hooves than do cows in tie stalls.

Papillomatous digital dermatitis ("Mortellaro's disease") is a major cause of lameness in dairy herds (Read and Walker, 1998). Morbidity may reach 75% within a few months. Epidemiological case-control studies in California dairy herds found that muddiness of corrals was strongly linked to a high prevalence of the disease (Rodriguez-Lainz et al, 1996). In the United Kingdom and Europe, poor foot hygiene has also been associated with the occurrence of the disease in winter-housed cattle (Blowey, 1994). In addition to muddy corrals, the importation of heifer replacements from affected herds is a risk factor (Rodriguez-Laing, 1996). In Chilean dairy herds, cows on farms that bought heifers in the past 10 years had a threefold increase in the odds of the disease compared with those on farms that never bought heifers (Rodriguez-Lainz et al, 1999).

The behavior of dairy cows has been suggested as a possible risk factor in cattle lameness, and lying down is considered an important part of the behaviour of dairy cows. Field observations suggest that in a herd with a high incidence of laminitis and other hoof lesions, the cows and heifers spent longer periods standing than those in a comparable herd with less lameness. Some heifers may stand for long periods and most will become lame. Heifers introduced suddenly to unfamiliar cubicles (free stalls) may spend most of their time standing on concrete floors, which could cause a localized circulatory disturbance and predispose the hoof to sole ulcer (Greenough and Vermunt, 1991). The times spent lying and standing and the frequency of lying have been associated with the incidence of sole lesions (Singh et al, 1993b). It is suggested that in countries that house cows during the winter months, the welfare of cows could be improved by training first-lactation heifers to use cubicles and by providing large well-bedded cubicles.

In small-scale dairy farms in Kenya, the prevalence of lameness was 11.7%, and the most important farm characteristic associated with increased prevalence of lameness and foot lesions was confined housing (Gitau et al, 1996).

Holstein-Friesian cows on pasture need 240 cm × 120 cm lying space and a further 60 cm lunging space for rising (Faull et al, 1996). By these standards of space requirements, 87% of the cubicles in 37 dairy herds were too short and 50% were too wide or too narrow. Over 1500 observations of cows lying down, rising, and standing found that only 12% of the cubicles permitted adequate freedom of movement; 91% of the top partition rails were judged to be too low, and 70% of the bottom rails were too low or too high. The curb was too high in 76% of the cubicles. As a result, 10% of the cows appeared moderately or severely restricted when lying down—33% when rising and 55% when standing. Over 2000 cubicle beds were examined; 75% had a concrete base, and of those, 63% had too little bedding and 11% almost none. The incidence and prevalence of lameness were associated with limited borrowing space (at the side and front of cubicles), low bottom rails, and inadequate bedding. Most of the indoor and outdoor walking surfaces were unsatisfactory. The indoor walking surfaces are concrete and too smooth, and the outdoor walking surfaces are commonly too rough.

The effect of free stall and straw yard housing of the behavior, production, and hoof health of dairy cows has been examined. In straw yards cows spent longer lying down and feeding than did cows in free stalls (Phillips and Schofield, 1994). Cows in free stalls had a reduction in heel depth, which predisposes to lameness. Cows housed in straw yards will spend 10 hours per 24-hour period lying down and ruminating (Singh et al, 1994). The effects of overcrowding on claw health of first-calved Friesian heifers indicate that reduced lying time acts as an exacerbating factor in the development of claw lesions (Leonard et al, 1996).

Lameness may be associated with the type and maintenance of the farm tracks to and from the pasture, the patience of the stockperson in handling, and herd size (Hemsworth et al, 1995). Hematoma of the heel causing lameness in dairy cattle has been attributed to traumatic injury incurred while the cows walked from the pasture to and from the milking parlor when the heel could have injured (Blowey, 1997).

In Australia and New Zealand, foot lameness in dairy cattle is most frequently associated with overworn, bruised soles or stones becoming embedded in the interdigital cleft. The most important environmental factor affecting lameness is the farm track to the pasture. The track should be surfaced with a fine, nonabrasive material to ensure drainage from the center of the track. Cows walking on the track should not be hurried more than necessary; they should be allowed to choose their steps as they move along the track (Chesterton, 1989).

Frequency and Adequacy of Foot Trimming. The undue mechanical pressure on the solar corium that occurs when too much weight is borne by the pedal bone, or when the corium is inadequately supported by the horny sole, predisposes to sole contusions. This is more likely to occur in untrimmed claws and with longer toes as well as where more load bearing is placed on the softer, midsole region. Trimming of hooves reduces the hardness of the heel bulb center. A reduction in the load bearing of the heels because of trimming of the toe length maintains a soft heel bulb that

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acts as a cushion, spreading the load evenly and absorbing energy (Smit et al, 1986).

The length of the toe is positively correlated with the lameness score. The trimming of hooves can have significant effects on the incidence of lameness in dairy cattle. To maintain a short toe length and steep angle of toe, which appears necessary to reduce lameness, regular trimming is required, at least once per lactation. The best time for trimming seems to be before calving. Using this approach, hoof shape is at its optimum in early lactation, when the incidence of lameness is highest (Manson and Leaver, 1989).

For the details of foot trimming of cattle, the reader is referred to the excellent publication by Toussaint Raven, "Cattle footcare and claw trimming" (1985).

Individual-Cow Risk Factors.

Age and Stage of Lactation. The population at risk in most studies are adult cows, including first-calf heifers. The prevalence of lameness is highest during the first 3 to 4 months of lactation, which coincides with the high level of energy intake and negative energy balance (Rowlands et al, 1985). In Quebec, 66% of lesions appeared during the first 3 months of lactation (Choquette-Levy et al, 1985). The increased incidence of sole hemorrhages and laminitis in periparturient cattle is indirect evidence that events relating specifically to calving are likely to be crucial risk factors (Bergsten and Frank, 1996a,b). Some observations found a strong positive association between 61 and 120 days postpartum and the presence of sole disorders (Vaarst et al, 1998). Claw hemorrhages are uncommon in first-calving heifers 4 weeks before calving, but the extent and severity of hemorrhages increase after housing and calving, with lesions in the white line being most severe at 9 weeks, and in the sole at 14 weeks after calving (Leach et al, 1997). Claw lesions occur commonly in dairy heifers shortly after calving (Whay et al, 1998). It is hypothesized that an initial insult to the corium primarily affects the laminar region and that corium damage increases with the resulting alteration in the physical forces on the sole. Changes in the white line do occur during the first lactation (Kempson and Logue, 1993). Different risk factors for sole disorders in first and later parities have been found, which suggests the importance of distinguishing between the development of sole disorders in first parity and older cows (Vaarst et al, 1998).

Previous Lameness in Affected Cows. Previous treatment for lameness in a cow appears to be a risk factor for acute sole hemorrhage (Vaarst et al, 1998).

Body Weight and Body Condition Score. Body weight and body condition score (BCS) have been associated with clinical lameness in some dairy herds (Wells et al, 1993b). In one survey, each 100-kg increase in body weight was associated with a 1.9-fold increase in the odds of clinical lameness. There was a positive association between prevalent clinical lameness and heavier body weight, lower BCS, and shallower slope of rear lateral claw angle (Wells et al, 1993a,b). A lower BCS was associated strongly with clinical lameness, which may be a result of, rather than a cause of, lameness. Body weight at calving was a significant risk factor for acute hemorrhage in cows from parity 2 upwards; a strong negative association between acute hemorrhage and a body weight more than 50 kg below the herd average (Vaarst et al, 1998).

Growth Rate of Heifer Replacements. The calving heifers at too early an age may contribute to an increased incidence of laminitis and its sequelae. The examination of the hind hooves of dairy heifers from 4 to 24 months of age revealed that subclinical laminitis characterized by sole hemorrhages can occur in the hoof horn of calves as young as 5 months of age. There was evidence of sole hemorrhages deep within the sole 30 to 35 days after calving, which by 70 days postpartum had developed into extensive sole and white line hemorrhages. There was often a deep hemorrhage at the site of sole ulcers. Sole overgrowth was also present in all heifers. Thus subclinical laminitis of varying degrees can be common during the early growing period of young dairy heifers (Greenough and Vermunt, 1991).

Breed and Genetic Predisposition. Breed disposition and genetic composition to lameness have long been of interest to the dairy cattle industry. Dorsal angle claw angle has been used as a repeatable measure of hoof shape with a heritability high enough for genetic change. However, its relationship with lameness or claw abnormalities has not been shown conclusively. Because 70% to 85% of rear foot lesions occur in the lateral claws, an association between these lesions and rear lateral claw angle has been suspected (Wells et al, 1993a,b). Among the conformation type traits that may be correlated genetically to clinical lameness, foot angle, rear legs (rear view), and rump width had strongest associations with clinical lameness (Boettcher et al, 1998).

Control of Lameness in Dairy Cattle. The control of lameness in dairy cattle is empirical based on field observations. A number of guidelines are recommended.

Improved Awareness of the Problem. There is a need to improve the level of knowledge that farmers have about lameness. This includes recognition of lameness, recording of lameness cases, the causes of lameness, early treatment of lameness cases, and the principles of prevention of lameness in dairy cattle (Mill and Ward, 1994; Kossaibati and Esslemont, 1997).

Early Diagnosis and Treatment. To accurately document a herd problem of lameness, the feet of all cows must be examined. To establish an adequate diagnosis and the actual frequency of foot lesions, the foot has to be examined thoroughly. This is ideally done at the time of routine foot trimming. The methods for assessment of lesions of the sole and white line have been described (Leach et al, 1998). All lame cows should be examined and treated as soon as possible. Isolation in a well-bedded hospital pen for several days may be necessary. A record of each lame cow and the diagnosis should be kept. Details for the treatment of specific diseases of the feet are available in other textbooks such as "Lameness in cattle" (Greenough, 1997).

Cubicle Design and Bedding. Cubicles or free stalls must be designed to meet the requirements of the cows in the herd. Cubicles must be of the correct design so they do not cause injury. The design specifications were presented earlier in this chapter. *Unnecessary prolonged weight-bearing by the feet and trauma to the feet must be reduced. Cows must be provided with comfortable places for lying down for up to 12 hours/day.*

There must be a sufficient number of free stalls for all cows to lie down at the same time. Training animals to use the free stalls is important. Heifers that have been reared in free stalls adapt more quickly when they join the main herd. Heifers often find it difficult to adapt to the main herd because of the stress of parturition, aggressive behavior of other animals, and dramatic changes in feeding behavior. If they are exposed to a new and uncomfortable environment, they may spend excessive periods standing and thus develop lameness.

The bedding used in free stalls must be comfortable, clean, and well maintained. The bases of cubicles must be kept clean and dry by scraping out manure at least twice daily and renewing the bedding as necessary. Many different materials have been used as bedding including earth, sand, sawdust, shavings, fabricate cows mats, and used tires. Chopped straw or sawdust is commonly used as bedding in the United Kingdom. It is suggested that mats or mattresses provide more comfort (Kossaibati and Esslemont, 1997). Some studies have found that cows do show a preference for

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lying on certain materials such as mats and sawdust (O'Connell and Meaney, 1997). The important principles are that the bedding must be soft and comfortable and easy to keep clean.

Indoor and Outdoor Walking Surfaces. The floor surfaces of the indoor alleyways between the rows of cubicles are usually made of concrete, which may be too smooth or too rough. The frequent scraping of the alleyways often produces a very smooth surface, making it slippery and insecure for cows (Faull et al, 1996). When walking on smooth surfaces, cows may have a shuffling gait that may affect the type of wear on the sole and white lines and increase the duration of contact. Concrete alleyway surfaces should have a good grip without coarse projections. This requires mechanical tamping when the concrete is being poured to ensure that the aggregate is sufficiently covered by "fines" and provides a satisfactory surface. Exposed aggregate made from hard, sharp-edged stone creates an unfriendly surface and an unsuitable material for walking.

Outdoor cow tracks from the milking parlor to the pasture must not be hard or rough. Cow tracks should be made from soft materials such as wood chips or grass lanes without stones and other hard substances. Dairy cows show a marked preference for soft bark walkways as opposed to concrete or stone tracks. The walkways are constructed by excavating the ground to a depth of 0.5 m and a width of 1.0 m. The trench is filled with a specialized geotextile membrane, as used in road construction, and a drainage pipe is run along the base. This is surrounded by stone aggregate, with fine stone towards the surface, and covered by a second reinforced geotextile membrane. Finally, 50 to 100 mm of cundy peelings, a type of bark chipping, are placed on the surface. The improved comfort causes a marked increase in the speed of walking (Blowey, 1997). Specific track designs made from tough, synthetic, nonwoven fabric are now available for construction of cow tracks.

Emphasis should be placed on maintenance of the surface of cow tracks and on the patient handling of animals before and during milking; these are high-priority strategies in which changes could reduce lameness in severely affected herds (Chesterton et al, 1989).

The walking surfaces adjacent to feeding areas, watering areas, and gateways need to be maintained with adequate drainage and scraped clean of stones and other hard loose objects.

Inspection of the housing facilities can be performed, and recommendations and improvements can be made. Cow comfort can be improved and the incidence of lameness decreased (Goodger et al, 1996).

Sanitation. Floor surfaces and alleyways must be cleaned as necessary to remove collections of urine, water, and manure that contribute to constant wetting of the feet.

Foot Bath. Foot baths containing formaldehyde or copper sulfate solution have often been advocated to control foot disease in cattle (Davies, 1982), but this recommendation is empirical. No documented information exists on the effectiveness of footbaths for the control of diseases of the feet of cattle. The regular use of a footbath has been recommended in herds with a high incidence of interdigital disease, heel erosion, and sole ulceration. With a footbath containing 1% formalin (1 part formalin:39 parts of water), the cows can be walked through the bath after each of four successive milkings; this process is repeated weekly (Davies, 1982). However, results have been variable, perhaps because of the accumulation of excessive amounts of feces on the feet of the animals. This results in contamination of the footbath, rendering the solution ineffective. Another reason may be that the lesions are not caused primarily by infectious agents. It appears logical that, for maximum effect in problem herds, the feet of the animals should be cleaned with a pressurized spray of water before the animals are walked through the foot bath.

Papillomatous digital dermatitis is most effectively treated with topical application of an oxytetracycline solution on a individual cow basis (Hernandez et al, 1999). Lincomycin hydrochloride solution used as a topic spray daily for several consecutive days is also successful (Shearer, 1998).

Footbaths should be located in a passageway 1.0 to 1.2 m wide on the return route from the milking parlor. It is useful to have two baths in series, the first containing water to wash the feet and the second to reduce contamination of the astringent. The specifications for a footbath are at least 300 cm long, 100 cm wide at the top, 60 cm wide at the bottom, 30 cm deep, sloping ends, nonslip surface, solution depth of 17 cm, and the exit area sloping back to the bath. Adherence to these specifications reduces the amount of solution used, reduces the loss of solution, and allows emptying the footbath with a brush. It should open onto a large, clean area to prevent immediate recontamination of feet with feces. Astringent chemical solutions of either 5% copper sulfate or 5% formalin should not be used more than twice a week, even for herds with soft feet. Use should be even less frequent as the feet harden. The skin of the coronary band and the soft tissues of the claw should be monitored in representative cows for evidence of chemical injury.

Regular Foot Trimming. Surveys have found that only about 20% of healthy dairy cows have their feet trimmed regularly.

The feet of all cows should be examined and trimmed (if necessary) at least once annually. The claws of the hind feet of housed cattle should be examined and trimmed midway through the housing period. Underrunning of the bulbar horn (erosion ungulae) and pododermatitis circumscripta (Rusterholz sole ulcer) are more common in housed cattle and can be controlled by preventive hoof trimming (Andersson and Lundstrom, 1981). Commercial foot trimmers are now becoming popular. They visit the farm with a hydraulic trimming table and foot trimming instruments and trim the feet of all cattle in the herd during one visit. Veterinarians can also supply this type of service as part of a health management program. However, some field trials have indicated that routine foot trimming alone does not significantly reduce lameness (Arkins and Hannan, 1982). More field research is needed on this subject.

Balanced Ration. The diet of high-producing dairy cows should be balanced with the inclusion of sufficient fiber to minimize rumen fermentation disorders.

Nutritional Management For Replacement Heifers. The ration for replacement females should be managed to optimize the growth rate.

Monitoring Lameness and Its Risk Factors

Because of the multifactorial causes of diseases of the feet, especially the pathogenesis of laminitis and its sequelae, the problem of lameness in the field needs to be examined using an epidemiological approach. With information from computerized health management databases, it is possible to study the characteristics and predisposing factors for a large number of lameness cases. Several identifiable variables can be evaluated simultaneously (Box 12-1).

It is clear that lameness in cattle is a complex subject. A detailed description of individual lameness conditions and the predisposing factors has been published (Greenough, 1997). It is also clear that management of the cows' environment can have a substantial impact on the occurrence and

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BOX 12-1

Characteristics and Predisposing Factors for Lameness

- Seasonal effects
- Type of housing (loose housing versus tie stalls); design of free stalls
- Quality of the floor: concrete floors, slatted floors, stony tracks
- High-energy, low-fiber diets in early lactation
- Handling of cattle at milking time or at other times when they are being crowded
- Lack of exercise during winter housing, causing circulatory stasis in the foot
- Prolonged wet conditions, which affect horn quality
- Inadequate foot trimming
- Unhygienic conditions, which cause irritation and contamination of the skin tissues of the feet
- Overgrown feet, in which excessive horn is prone to erosion

severity of lameness in dairy herds. Veterinarians involved in dairy health management programs should be familiar with epidemiological associations between the environment and lameness. The evaluation of records on the incidence of lameness and an assessment of environmental and nutritional influences should be incorporated into the health management program.

Internal Parasitism

An important environmental management challenge as part of dairy herd health programs is the control of internal parasites. Veterinarians involved in dairy health management should have the necessary depth of knowledge about the elements that must be addressed in crucial decisions on worm control. It requires a good understanding of the epidemiology and biology of the parasites, the influence of seasonal conditions, the effectiveness and limitations of available drugs, and the costs and benefits of various control strategies. This information should be considered in context with the nature of the individual farm and its management.

It is not unusual for health management advisors to have a blanket recommendation on parasite control for all herds. However, no single recommendation applies to every farm; each herd must be evaluated individually. A customized worm control program should be devised for each farm. It should be based on the practitioner's general knowledge of internal parasitism and on information on the farm's management, grazing history, and seasonal conditions. The practitioner should also consider each age group of cattle separately and provide specific control programs for adult cows, replacement heifers, and calves (Herd, 1991).

There are two key issues that determine parasite infection levels and ultimately dictate the design of an effective and prophylactic parasite control program. First, it is important to determine the parasite immune status of each group of cattle. Second, the likely degree of pasture infectivity and potential exposure to internal parasites are also important. Information on these two issues requires an ongoing knowledge of the individual farm. In addition, the results of appropriate quantitative laboratory techniques are useful, as long as the results are interpreted in relation to the herd's history and management.

Factors Affecting Parasite Infection Levels

Immune Status. Adult dairy cattle on a sound nutritional program usually have a high degree of acquired immunity to internal parasites. Laboratory evidence indicates a low level of worms per animal (<3000) and low mean fecal egg counts (<10 eggs/g). Dairy cows may exhibit a slight periparturient depression of immunity to worms. Fecal egg counts may rise slightly, from a mean of about 5 eggs/g to about 20 eggs/g after calving. This increase is usually epidemiologically insignificant. Cattle younger than 2 years of age may have little immunity to worms. Large worm burdens (>100,000) and high fecal egg counts (>100 eggs/g) often occur. These levels of infection are associated with significant losses in growth rate and even with mortality.

It is not uncommon for a whole group to fail to develop adequate immunity to worms because of lack of exposure. This includes dairy cattle that have been raised in confinement, in arid regions, or in drought conditions during which infective larvae failed to survive in pastures. These cattle are later susceptible to worms if moved to a contaminated pasture. Animals that were once strongly immune can lose immunity to worms through poor nutrition, concurrent disease conditions, or lack of exposure. Cattle that lose their immunity can exhibit high fecal egg counts and represent a serious source of pasture contamination.

Dairy replacement heifers during their first year of grazing are usually susceptible to worms. In addition, they are likely to be exposed to significant pasture contamination if they are grazing pastures that were previously occupied by similar batches of calves.

Pasture Infectivity. Housing and climate strongly affect the epidemiology of worm parasites in dairy cattle. Because pastures perpetuate parasites, the greatest risk of infection occurs in nonimmune cattle on pasture. In contrast, cattle housed continually in confinement are rarely exposed to parasitic larvae, except for *Nematodirus* and *Strongyloides* sp.

The degree of pasture infectivity is strongly influenced by the previous grazing of a pasture. Young, untreated, nonimmune animals cause the greatest pasture contamination with worm eggs. The degree of infectivity of a pasture is also strongly influenced by seasonal environmental conditions. Warm, wet conditions favor hatching, development, and migration of infective larvae from feces to pasture. Drought conditions enhance larval mortality.

Once a pasture becomes highly infective, the larvae survive long periods and pose a threat to all grazing animals. In the northern United States and Canada, larvae commonly survive until late spring of the year after hatchings. In the southern United States, larvae survive well through the autumn, winter, and spring. However, they do not survive in high summer temperatures. Pasture and manure management can have a significant impact on the level of inactivity.

A review of the literature suggests that *Ostertagia ostertagi* appears to be the most prevalent parasite among adult dairy cattle in temperate regions of the world. *Trichostrongylus axei* and *Cooperia* sp. are frequent isolates associated with ostertagiasis (Bauck, 1991). Abomasal worm burdens are present in a high percentage of adult cows, and some cows may have relatively high levels. There is a seasonal pattern of inhibition of *O. ostertagi*. The seasonal inhibition is moderated somewhat by age-related immunity. However, it is nonetheless essentially the same in adult animals as in yearlings. Fecal egg counts in cows are generally low throughout the year. However, there is a rise in fecal egg counts associated with parturition, suggesting a reduction in host immunity at this time. If calving coincides with seasonal resumption of development of inhibited *O. ostertagi*, the rise in fecal egg counts may be substantial and indicative of a significant infection (Michel et al, 1979).

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Relationship of Parasitism to Performance and Anthelmintic Treatment

The effect of subclinical parasitism on milk production in dairy cows is highly controversial. There is no definitive evidence that low worm burdens in immune cows cause a reduction in milk production. However, a review of studies published on the effects of anthelmintic treatment of dairy cows has revealed extreme disparity in the results of benefits in milk production (Bauck, 1991). Most publications almost invariably begin with a statement such as "deworming of dairy cattle with various anthelmintic treatments in different geographical regions has had inconsistent effects on milk production. Some reports show deworming increases milk production, whereas others show a decrease or no change in milk production" (Block et al, 1987).

The results of more than 80 experiments on gastrointestinal parasitism and effect of anthelmintic treatment on milk production in dairy cattle have been reviewed (Gross et al, 1999). Abattoir surveys of culled dairy cows, fecal egg counts in milking cows, and serological tests and worm counts in cull cows in milk production studies were collated to assess the level of parasitism in dairy herds. The studies were divided into four general categories: induced infections in previously uninfected cattle; naturally infected cattle treated in mid-lactation; naturally infected cattle treated one to three times during the dry period and/or just before or after parturition; and naturally infected cattle treated repeatedly from early lactation or given strategic treatments throughout the year. In most studies, the milk production of anthelmintic-treated cattle was compared with that of untreated animals. The anthelmintics used included members of the organophosphate, benzimidazole, imidazothiazole, and macrocyclic lactone groups. Overall, the studies found that grazing dairy cattle are likely to be infected with gastrointestinal nematode parasites, usually *O. ostertagi* and *Cooperia* sp. These infections may be present as inhibited larvae, and a periparturient or spring rise is associated with their emergence. There is, at present, no reliable means of determining if a cow or herd is parasitized subclinically at a level sufficient to interfere with milk production. In 80% of trials, there was an increase in milk production after anthelmintic treatment, with a median increase of 0.63 kg/day. In each of four categories, a majority of the studies showed that anthelmintic treatment increased milk production (Gross et al, 1999).

There are many difficulties in the interpretation of the data from the published studies. There are often highly significant between-farm and within-farm factors responsible for differences in milk production, irrespective of any treatment response. There is marked inherent variability in milk production among cows. It is affected by a host of variables, including genetics, nutrition, and environment. In addition, there has been little consistency in the protocols used for the evaluation of treatment effects. The timing and frequency of treatment, cattle management practices, and the response variables measured were considerably different from study to study.

The predominant finding in the literature is that the effects of anthelmintic treatment are greatest in the periparturient period. Milk yield in postcalving dairy cows is closely correlated with energy balance. In addition, the body condition of cows at calving may also be a determining factor in subsequent milk yield, because body fat reserves represent a source of energy for the lactating cow. There is evidence that parasitism in livestock can affect both feed intake and the efficiency of nutrient utilization. It follows that parasitism before and at the time of calving can lead to reduced milk yield (Bauck, 1991). Experimental parasite infections of dairy cattle at parturition and in midlactation have indicated that the effect of parasitism on milk yield ıt significant in the first 100 days of lactation (Barge ibbs, 1981). Many studies have evaluated the effect of parasitic treatment at the time of parturition on subsequent milk yield. Although a negative response or no effect is reported in some experiments, the majority of studies have indicated a positive effect. However, the factors that determine which cows and herds have the most significant benefit remain difficult to determine.

A further difficulty in interpreting the results of clinical trials is the effect of treatment against inhibited *O. ostertagi*. Compounds with little or no activity against this component of the worm burden at certain times of the year could allow subsequent development of these inhibited larvae at some time after calving. Thus the expected increase in milk production for these treated animals would not occur. In one study that evaluated the effects of treatment with ivermectin during the dry period, the level of *O. ostertagi* antibodies measured at the end of the previous grazing season was correlated with the magnitude of the response to treatments (Ploeger et al, 1989). In this experiment higher-producing cows had a greater treatment response, the response was highest in early lactation, and the improvement was most notable during the season when a large portion of the worm burden of calving cows should have inhibited *O. ostertagi* larvae. Treatment with an appropriate anthelmintic at dryoff appears to show great promise, and further research is indicated.

Monitoring Internal Parasite Levels in Dairy Herds

As has been emphasized repeatedly in this text that monitoring performance, and factors that affect it, is the key to an effective health management program. With respect to internal parasitism, it is important to monitor the degree of immunity to worms and the severity of pasture contamination (Herd, 1991). It is also important to monitor the incidence of clinical and subclinical parasitism. These parameters should be assessed in context with the monitoring of productivity and growth, as well as the incidence of other diseases. Based on the results of these monitoring methods, a farm-specific parasite control program can be developed.

One research study has indicated that determination of fecal egg counts, performed and interpreted correctly, is a valuable monitoring tool for assessing immune status and the degree of pasture contamination (Herd, 1991). When considered in relation to the history and management of the farm, fecal egg counts also provide an ongoing indicator of the success of the worm control program. The efficacy of the drugs used and the need for any changes to ensure low pasture contamination can be determined. Feces should be monitored by an appropriate quantitative fecal flotation technique (Herd, 1991). Individual fecal samples should be taken at critical periods from an appropriate number of randomly selected animals in each age group. The number of animals to be sampled depends on the size of the group, and this can be calculated (Martin et al, 1987). A wide variation in counts from the samples from one herd, however, indicates the need to sample a larger group of animals. It should be emphasized that nonquantitative fecal flotation techniques have little diagnostic value in dairy cattle.

Fecal samples taken on the day of treatment can be used to assess whether the previous treatment was successful in suppressing fecal egg counts for the full interval between treatments. Fecal egg counts are also useful before cattle are moved to a new pasture. If the counts are high, the cattle should be treated to ensure that little contamination is carried into the new pasture. In this way, clean cattle going into a safe pasture may be protected for months instead of only

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for a few days. Adult cattle require fewer egg count determinations than young cattle because of acquired immunity to worms. However, a suspected loss of immunity can be detected early by a rise in egg counts.

Control of Internal Parasitism in Adult Dairy Cattle

An internal parasite control program should be planned for the specific needs of each farm. Also, different age groups have different control needs. The specific details of parasite control in replacement heifers are discussed in Chapter 9. This is an important aspect of heifer health management. Much less is known about designing and monitoring a parasite control program for adult dairy cattle.

The use of pasture as a nutritional source is becoming infrequent in dairy production systems in North America in contrast with Australia, New Zealand, and some regions of Europe. However, it is common to use a small, grassy area (1 to 5 hectares) as a summer exercise area and dry lot. This area is used continuously year after year. There is considerable potential for parasite infectivity to develop in this small field. Thus the need for a parasite control program in the adult herd should not be dismissed.

Important considerations in determining the nature of a control program should be the results of quantitative fecal egg counts, the production performance, and the management system. Fecal egg counts should be interpreted in the context of levels indicative of good immunity and low pasture infectivity. Counts that deviate from an expected pattern may indicate a need to consider management changes or a prophylactic anthelmintic program. Based on the available literature, the use of ivermectin at dryoff shows considerable promise as a control program (Ploeger et al, 1989). More research is needed, and label withdrawal criteria must be followed. Alternatively, deworming at parturition has been effective in a number of studies (Block et al, 1987; Fetrow et al, 1985). It may be appropriate for practitioners to conduct within-farm or within-practice efficacy evaluations to determine the most suitable approach. With the use of computerized herd data management programs, cohort or case-control analysis is straightforward. As well as an anthelmintic program, steps to alter the environment to reduce pasture infectivity should be taken (Herd, 1991).

Control of Flies In and Around Dairy Barns

Changes in animal production systems often favor fly populations. This is usually the unplanned result when the problem of fly propagation is not considered during the design of facilities that enhance the efficiency of production.

Fly control measures must evolve to accommodate changing animal production and housing practices. The species of flies, their relative abundance, and the success of fly control measures are affected by animal husbandry practices, especially housing and manure-handling systems. A multimethod management program is necessary to provide a rational approach to fly control. This involves a mixture of cultural, biological, and chemical control measures adapted to the production system. In order to use this approach, considerable knowledge about the fly species, their biology and behavior, their parasites and predators, manure management techniques, insecticides, and insecticide application methods is required (Axtell, 1986).

Cultural Methods. Cultural control of fly populations is basically the manipulation of the abiotic factors that suppress fly numbers. In other words, this means proper management of manure, feeds, and facilities. Removal of the manure frequently and thoroughly, or keeping it dry, reduces the habitat for fly larval development. The prevention of feed spoilage and keeping the feeds dry reduce habitats for fly breeding. Spillage around the bases of silos and feed bunks, improperly covered silage, and unprotected hay bales are all prolific fly breeding sites when there is sufficient moisture.

Preventing moisture in the potential fly breeding areas is the critical cultural factor in fly control. Watering areas are a potential source of moisture if those systems are poorly designed or maintained. Concrete aprons around feed bunkers and waterers encourage runoff, simplify cleaning, and lessen fly breeding.

Ventilation and airflow in animal housing affect the rate of evaporation. This may be a critical factor in producing sufficient drying to suppress fly breeding. Housing a large number of cattle in a confined space contributes substantial moisture to the air. Without proper ventilation and airflow, ideal habitats for adult fly survival and moist fly breeding media are created. On the other hand, the compactness of manure affects the amount of fly breeding. Trampling and compacting the manure and bedding in a pen with high animal density render the habitat poorly suited for fly breeding. Compacting and covering manure piled for storage also reduce fly populations. Housefly populations are reduced by the excessive dilution of manure with water. This concept is used in outdoor waste lagoons in conjunction with flushing systems for manure removal in free-stall dairy housing.

Biological Methods. In dairy production systems with prolonged accumulations of manure, a diverse fauna of arthropods develops. Among these are species of mites and beetles that prey on fly eggs and larvae. Also, there are a number of species of parasite that develop in the fly pupae and, as a result, kill the flies. The maximum benefit from predators and parasites is achieved with dry manure. In very wet manure, predators cannot move about effectively to find and consume the fly eggs and larvae. Therefore the cultural practices designed to promote manure drying in order to reduce fly breeding at the same time encourage predators and parasites of immature stages of the flies. Manure removal schedules should be staggered so that the predator and parasite populations are not decimated. Chemicals for fly control should be used selectively to preserve the predator and parasite populations.

Chemical Methods. After maximum effort to suppress fly numbers by proper cultural and biological methods, there is still often a need for use of insecticides to achieve the degree of fly control desired. The most effective insecticide use is in an integrated control program in conjunction with cultural and biological methods. If fly suppression by these methods is maximized, then the effectiveness of the insecticide treatments is enhanced. The rate of development of fly resistance to the chemicals is also reduced.

There are two general methods of controlling fly populations by the use of insecticides. Chemicals used as adulticides are available as baits, surface sprays, and mists. Larvicides can be used for spraying breeding sites and as feed additives. Baits consist of an insecticide mixed with some attractive substance, such as sugar. Surface sprays applied to the walls and ceilings of buildings are designed to provide a long-lasting toxic surface where flies rest. Adult fly control can also be attempted with the use of mists. This provides temporary control, because only the adults exposed at the time of the application are killed. Misting is most effective when ventilation is limited.

Larviciding the manure or other fly breeding sites is accomplished with the same types of equipment used for residual surface sprays. A coarse spray and high volume are required. However, larvicidal treatment may be a useful adjunct to other control methods. Larviciding can also be accomplished by incorporating an insecticide into the feed of

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the animals. However, few insecticides are registered for this purpose.

Any insecticides that are used as part of a fly control program must be labelled and registered for their intended use. Extreme caution should be exercised in dairy facilities to be sure that only approved insecticides are used and label instructions and restrictions are followed. Another factor is resistance of flies to insecticides. Resistance to new insecticides after they are in widespread use has developed rapidly among fly populations, especially the housefly. Many standard insecticides formerly used for fly control are no longer effective. Reliance only on the use of insecticides seldom provides a satisfactory control program. The use of insecticides should be in conjunction with maximizing the cultural and biological measures of control.

Monitoring Fly Populations. In order to design and evaluate a fly control program, some method of monitoring the adult fly population in and around a dairy production facility is needed. Systematic monitoring provides a measure of the success or failure of control methods. It also serves as an early warning system so that changes can be initiated before populations increase wildly. Casual, subjective observations of fly numbers can be misleading. Systematic monitoring is an objective and reliable component of an integrated fly control program. Methods for monitoring populations of adult flies include fly grids, resting counts, sticky fly ribbons, baited jug traps, and spot cards. These methods are primarily used to obtain a measure of the number of houseflies in a facility. It is also important to monitor for fly larvae and pupae to determine specifically where the flies are developing.

Specific Fly Control Measures for Dairy Herds. Dairy cattle facilities have several potential major fly breeding areas. The relative importance of each area on a specific farm depends on the facilities and management used. Specific fly control measures are aimed at dealing with these fly-breeding areas. The most important fly control measures are summarized in Box 12-2.

BOX 12-2

Fly Control Measures

Clean maternity stalls, calf pens, and hutches frequently.
Because the life cycle of the housefly is 7 to 10 days, weekly cleaning can drastically reduce fly propagation.
Move calf hutches frequently. This allows the ground to dry out and limits fly breeding.
Enclose the space under bunk feeders. This prevents spilled feed from accumulating in this area.
Provide curbs and a concrete surface in the loafing area.
Clean stanchions and gutters frequently.
Scrape and clean the loafing area frequently.
Provide a concrete apron around feed bunks and waterers.
Provide a sloped and curbed concrete area for loading the manure spreader.
Cut the vegetation adjacent to manure pads.
Provide concrete channels and a settling basin for runoff water.
Keep the manure and runoff lagoon free of debris and floating solids. Do not overload the lagoon.
Clean up spilled feed on a weekly basis.
Use shelters over the feed bunkers.
Cover and store hay bales on a sloped concrete surface or on raised pallets.
Cover and seal the edges of horizontal silage silos and silage piles.
Clean around the base of tower silos and provide good drainage.
Use window screens on the milk house and milking parlor.
Use residual insecticide spray on the buildings and adjacent vegetation.
Monitor fly populations with fly bait stations.
Employ a misting program for adult fly control, as needed.

Behavioral Disorders

The behavior of dairy cattle has been reviewed (Arave and Albright, 1981). In one study the daily pattern of behavior and duration of various activities of confined cows appeared similar to the pattern and duration of activities in field-grazed and partially confined cattle (Hedlund and Rolls, 1977). Study of the behavior of dairy cows during a 24-hour period can help determine the requirements of a housing facility. The total amount of time lying down during a 24-hour period averaged 11 hours (range, 9 to 13 hours) on pasture, 11 to 11.5 hours for loose or free-stall housing, and 12 hours for stanchion stalls. Observations of dairy cows in total confinement revealed that, during 15 hours of daytime, they spent an average of 45% of the time lying down, 26% eating, 22% ruminating, 1% drinking, and 2% socializing (Hedlund and Rolls, 1977). Periods of eating, drinking, and social activity are most intense during and shortly after the morning and afternoon milking and feeding times. Conversely, periods of greatest recumbency, rumination, and rest occurred between feeding times, from midday to late afternoon.

These observations indicate that cows spend about 50% of a 24-hour day lying down. This emphasizes the importance of comfortable stalls, regardless of the system used. Cattle ruminate a total of 4 to 9 hours daily, in 15- to 20-minute periods. A large proportion (65% to 80%) of this time is spent in the recumbent position. Active sleep occurs in the cow only when she is lying down.

There is a close relationship among environment, behavior, performance, and disease (Collis et al, 1980). There is little information available concerning the diagnosis, prevention, and treatment of primary behavior disorders of dairy cattle, including behavioral causes of clinical disease and suboptimum performance. However, the major behavioral disorders of dairy cattle have been reviewed (Luescher et al, 1989). It should be emphasized that further study is needed in this area, and that the individual animal approach is ill suited for dealing with the behavioral problems of farm livestock. An epidemiological approach is necessary for these investigations. At the practical level, problems have to be dealt with on a herd basis. The behavioral problems of dairy cattle can be categorized based on their economic impact, even though exact figures regarding their prevalence and economic significance are largely unavailable.

Behavior Problems with Direct Economic Impact

Teat Sucking in Dairy Cows. This undesirable behavior may be displayed either by a cow sucking the teats of another cow or, more seldom, by a cow sucking her own teats. It leads to obvious economic loss. One report suggested that up to 50% of herds may be affected (Grommers, 1979). However, the general prevalence is assumed to be much lower than this figure. Cows within a herd form steady pairs for unidirectional or mutual sucking. This behavior may derive from intersucking in calves and may be related to housing conditions. It has also been associated with tongue rolling. Preliminary recommendations for prevention in-

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clude the early separation of calves from their dam, feeding calves using nipple drinkers, and avoiding grouping calves together until well after weaning.

Behavior Contributing to Teat Injury and Mastitis or Both. Housing conditions are an important causative factor for environmental mastitis (Klastrup et al, 1987). This relationship is largely because of the influence on cow behavior. Poorly designed tether systems and stalls that prevent cows from rising and lying down normally promote teat injury. Stalls that are too short may force the cows to lie on the edge of the stall and thus exert pressure on the udder. Poor freestall design can have similar effects. Other factors, such as stalls that are too narrow or allow too much freedom of movement, the lack of partitions between cows, and any factors hampering rising and lying down (such as slippery floors), may contribute significantly to the occurrence of teat injury on the neighboring cow and thus can lead to an increased risk of mastitis. Lying on bare or dirty concrete flooring is contrary to the cow species' typical preference. Lack of bedding in the lying area increases the risk of mastitis. (Unless an appropriate housing environment is provided, and behavioral changes occur, these problems can be long standing.)

Behavioral Causes of Injuries. Injuries to the brisket, carpal joints, hocks, stifles, hips, claws, and udder are far too common in modern dairy housing. In some herds these injuries occur in a high percentage of animals on the same anatomic location. This suggests that the cows' ability to adapt behaviorally to the housing conditions has been exceeded. These injuries may result from physical contact with the housing system, such as with poorly designed stalls (Cermack, 1987). Also, housing conditions may prevent normal movement patterns or stances when rising or normal body position when eating. A quantitative analysis of the incidence of these injuries, along with proper assessment of the housing system and behavioral observations, is necessary for a satisfactory solution.

Behavior Problems with Indirect Economic Impact. A large number of abnormal behaviors have not been linked directly to an economic impact. These problems are largely regarded as not warranting any action and are ignored. However, abnormal behavior can be an important indicator of deficiencies in management or environment. These deficiencies often have indirect effects on performance, efficiency, and health.

Quantitative Behavioral Changes Indicating Stress. A high frequency and long duration of lying down represent signs of stress caused by poor adaptation to the housing system. In addition, a higher than normal proportion of time spent standing while ruminating can be interpreted similarly.

Tongue Rolling. Tongue rolling is one of the few stereotypic behaviors displayed by ruminants. It is considered a vacuum-feeding behavior caused by a lack of roughage.

Behavior Problems Without Apparent Economic Impact

Many other abnormal behaviors occur in dairy production systems. These are largely induced by the environment or management. Their impact on economic return is thought to be negligible, but economic return is not always synonymous with the optimization of individual performance. In addition, biological performance is not always directly linked with economic performance. With these abnormal behaviors, two important points should be emphasized:

1. The linking of accurate behavioral observations and herd level information on performance needs to be studied to understand these associations further.
2. There is increasing public awareness of the effects of environment and management on animal care. Situations in which abnormal behavior occurs are often interpreted as indicative of an inappropriate level of suffering.

One management method under debate because of its effect on cow behavior is the use of electric cow trainers for the purpose of keeping stalls and cows cleaner, reducing labor, and simplifying management. The electric cow trainer consists of an electrified bar mounted horizontally a few centimeters over the cow's back and at right angles to the spine. If a cow arches her back when she is standing in the front of the stall, she contacts the cow trainer and receives an electric shock. This occurs during urination and defecation. The animals are supposed to learn to step backward before urinating or defecating so that urine and feces fall into the gutter and not into the stall. There is debate concerning the usefulness of cow trainers for the improvement of udder health. There is also a belief that cow trainers may induce abnormal behavior predisposing cows to teat injuries. Behavioral methods for assessing the influence of electric cow trainers on animal health have now been developed (Hultgren, 1991).

Social licking in cattle may have cleaning, tension-reducing, and bonding effects (Sato et al, 1991). The environmental conditions and management methods currently used in the dairy industry may have an impact on the social licking patterns of cattle. Some critics of animal agriculture and other groups in society believe that altering normal behavior is cause for concern.

Behavioral data can be incorporated into a dairy health monitoring effort. Behavioral observations may serve as sensitive indicators of specific deficiencies in the production system, thus reducing performance. The process of behavioral assessment involves several well-defined steps. An accurate history of the herd's behavior patterns should be obtained. This information should identify the nature of the problem, characteristics of the affected portion of the population, magnitude of its impact, seasonal or temporal patterns, and any corrective measurements that have been attempted. Careful observation of an animal's interaction with the environment and management system is important. Specific parameters relating to the physical, climatic, and social environments should be measured. For example, accurate measurements of the housing and population density should be collected. A comparison between the behavior in the production system being investigated and what occurs in the natural situation should be assessed. Finally, the assessment should be documented and an action plan established. Lactating dairy cattle are susceptible to a total change in environment. The movement of a lactating herd from one environment to a totally different one, with changed methods of feeding, milking, and housing, can adversely affect milk yield and milk composition for several days after the change (Nasi and Saloniemi, 1981).

Environmental Mastitis

Perhaps the most important problem associated with housing and environment in dairy herds is mastitis caused by environmental organisms. With the implementation of standard mastitis control practices, the prevalence of contagious mastitis has decreased. However, there is ample evidence that mastitis caused by environment streptococci and coliform organisms has not decreased. In fact, in relative terms, environmental mastitis has surfaced as a major problem.

Any environmental management program in dairy herds should be cognizant of the control of environmental mastitis. See Chapter 10 for mastitis control of dairy herds.

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BOX 12-3

Health Problems Associated with the Design of Facilities and Management of the Environment

1. Endemic respiratory disease occurs in calves raised indoors in close proximity to adult cows housed in poorly ventilated barns. Adult cattle are able to tolerate inadequately ventilated barns much more effectively than are young calves, which are highly susceptible to enzootic calf pneumonia. Outbreaks of acute respiratory disease also occur sporadically in adult cows kept indoors throughout the winter months in countries such as Canada, the United States, and the United Kingdom.

2. Lameness caused by diseases of the feet, such as sole ulcer and footrot, is associated with the quality of floors and environmental sanitation.* Acute traumatic injuries of the musculoskeletal system are associated with slippery floors. The level of the feeding manger bottom relative to the floor of the stall may be associated with traumatic injuries of the legs, feet, and udder.† A feeding level 16 cm above the stall floor causes the fewest injuries. A low feeding level forces cattle to spread their legs during eating, which may predispose to development of lesions of the feet.

3. An increased incidence of environmental mastitis is associated with unsanitary conditions because of the excess accumulation of manure on cows with inadequate bedding or the use of contaminated bedding.

4. Inefficient cow movement patterns among feeding, lounging, and milking areas represent a risk factor for an increased incidence of injuries because of inadequate design of facilities.

5. Insufficient space for each age group of animals in the herd may cause overcrowding. This increases the risk of the spread of infectious diseases and of problems with nutritional management.

6. Failure to provide separate feeds and feeding systems so that groups of cows can be fed according to their needs may lead to overconditioning or undernutrition as well as to subsequent health problems.

7. Inadequate housing facilities can limit the detection, identification, and handling of cows in heat. This causes suboptimum reproductive performance.

8. It is common to have an inadequate number of maternity box stalls for cows that are due to calve. Cows calving in well-bedded box stalls are less prone to traumatic injuries associated with slipping, falling, and recumbency as a result of parturient paresis. Calves born in clean, well-bedded box stalls have every opportunity to obtain liberal quantities of colostrum early in life.

9. Unsuitable housing for newborn calves can cause an increase in the incidence of infectious diseases, such as pneumonia and enteritis.

10. Inefficient milking parlor design can result in overmilking and an increase in the incidence of mastitis.

11. Inadequate, inefficient, and dangerous manure disposal systems can lead to gas poisoning during the emptying of manure pits as well as to possibly serious environmental contamination.

12. The lack of suitable animal holding and handling facilities for routine procedures and regular examination can limit the scope of health management programs and their impact on performance.

13. The availability and choice of suitable bedding materials, such as straw, wood shavings or sawdust, soil, newspaper, or sand, can be a problem. The bedding must be kept clean and dry in order to provide adequate comfort and limit environmental mastitis.

*From Blom JY: Traumatic injuries and disease in dairy cows in different housing systems. In *Livestock environment. II.* Proceedings of the second International Livestock Environment Symposium, Ames, April 20-23, 1982, Iowa State University.
†From Gjestang KE: The effects of environmental factors, floor design and materials on foot and limb disorders in dairy cattle. In *Animal housing injuries due to floor surfaces.* Proceedings of the Symposium on Cement and Concrete American Society of Agricultural Engineers, Berks, England, November, 1978, Fulmer Grange, Sloughs; and Gjestang KE: Feeding table geometry in relation to dairy cow comfort. In *Livestock environment. II.* Proceedings of the second International Livestock Environment Symposium, Ames, April 20-23, 1982, Iowa State University.

BOX 12-4

Criteria for Designing Dairy Housing

Site planning: placement, legal considerations, public relations
Services to and from the facility: electric power, water, transportation and access, communication, emergency services, feed storage and handling, required fuels, waste handling, drainage, animal disposal
The facility: climate control, space allocation, basic design, sanitation and contamination control, special equipment, instrumentation, animal behavior
Economics: construction costs of paramount importance

PROBLEMS ASSOCIATED WITH TOTAL CONFINEMENT

The complete confinement of a dairy herd is associated with many health and production challenges. Many of the housing features important for the maintenance of health and performance have been emphasized in this chapter. Some of the most important health problems associated with the design of facilities and management of the environment can be summarized in Box 12-3.

MAKING CHANGES IN HOUSING AND ENVIRONMENTAL MANAGEMENT

There are several important criteria for the design of any agricultural animal housing for comfort and productivity applicable to dairy housing. These include the major components shown in Box 12-4.

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BOX 12-5

Checklist for Developing and Implementing an Appropriate Plan for Expansion or Replacement of Facilities

Evaluate land area, topography, and local climate
Conduct water analysis and soil survey
Determine local zoning and building codes
Evaluate existing facilities and determine new buildings required
Determine layout of operation and cow and vehicle traffic
- Free-stall and milking parlor complex
- Treatment and maternity facilities
- Dry cow facilities
- Calf barns and replacement heifers
- Waste handling, storage, and drainage
- Feed storage and delivery system

Contact soil and water conservation authorities
Contact all regulatory agencies for approvals of plans
Develop preliminary construction plans and cost estimates
Develop preliminary long-term business plan and budget
Prepare projected cash flow statement
Define parameters for dairy modernization and expansion
- Livestock numbers (number of milking cows, heifers, and calves) and space requirements
- Labor and management requirements
- Establish time frame
- Refine budget

Review initial plan and financial needs with financing agency, if needed
Initiate key supplier network
- Financing agency
- Dairy design consultant
- Dairy equipment dealer
- Waste management suppliers
- Feeding system suppliers

Solidify professional services supplier network
- Veterinarian
- State and county extension services
- Regulatory officials
- General contractor

Obtain blueprints
Secure financing
Secure bids from contractors and suppliers
Award job to builders
Secure permits
Establish coordination system for suppliers
Finalize construction timetable and critical completion dates

Dairy producers contemplating expansion or replacement of their facilities need to use a checklist for the steps involved in developing and implementing an appropriate plan. One form of this checklist has been proposed by equipment manufacturers (Babson Brothers, Naperville, Ill) for the stepwise approach to planning and completing the building of new or modernized dairy facilities. Veterinarians and other farm advisors can have important roles in completing this checklist, shown in Box 12-5. Although this is not a comprehensive list of all that is involved, the principle is to use a stepwise approach.

INTEGRATING ENVIRONMENTAL MANAGEMENT INTO DAIRY HERD HEALTH PROGRAMS

The veterinarian should be aware of the housing and environmental factors that affect health and production in the dairy herd. The effects of housing and environment are complex, and there is usually no simple solution to a particular problem. For this reason the interdisciplinary team approach should be used to identify and solve problems. Agricultural engineers with experience in animal housing and ventilation systems should be consulted, and the veterinarian and engineer should visit the farm together. Detailed observations should be recorded, ventilation tests conducted, and a clear report of the recommendations given to the farmer (Anderson and Bates, 1982a,b).

In a comprehensive dairy health management program, environmental considerations should be an active, regular component of the process. Monitors for the effects of the environment should be established. Several indexes have been discussed throughout this chapter. The assessment of performance against farm goals and industry standards should be carried out. A plan of action should be developed and implemented. Ongoing regular monitoring should be performed to determine the effects of the environmental management program. Completion of this cycle is the integral process of health management, as described in other chapters.

SUMMARY

Providing an environment for animals that has a positive influence on the animals' health, welfare, and productivity is a goal of housing design. Essentially all aspects of the animals' surroundings and activities are taken into account, including ventilation, stalls and beds; access to feed and water; and walking surfaces. Enhancing the farmer's ability to fulfill the requirements of a sound management program is a function of the buildings and equipment on the dairy farm as well. Decisions about facilities must be preceded by a conscious determination of management style and management practices that may influence the final choice. Generally, the ultimate goal is to permit the genetically superior cows in dairy herds today to produce up to their potential. The facilities on the dairy farm should not be an obstacle to progress.

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CHAPTER 13

Health and Production Management in Beef Cattle Breeding Herds

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BACKGROUND

The history of cattle domestication has evolved over at least 10,000 years of recorded history, where it is evident that cattle played a pivotal role in sustaining physical, social, and spiritual needs of ancient cultures. Cattle were important in the process of civilization by allowing early man to make the transition from small bands of nomadic hunters to larger, self-sustaining settlements. The reasons why cattle became domesticated when many other herbivores did not is largely open to conjecture. However, it seems reasonable to assume that certain evolutionary behavioral traits should be more conducive to domestication than others. Such favorable traits are suggested to include the following: a social structure that favors the formation of large, hierarchical groups; the association of males with females (at least on a seasonal basis); male dominance; promiscuous mating behavior; sexual signaling by movement or postural cues and early bonding of young (Hale, 1962) as well as relatively large adult size and lack of territoriality (Tennessen and Hudson, 1981); and polygyny, tractability, and nutritional adaptability (Price, 1984, 1985). It is perhaps fortuitous that cattle fulfill most of these criteria admirably.

Today, cattle, representing a large number of biological types, are raised for a variety of purposes in widely differing environments. Beef cattle traditionally have been most represented in areas where intensive agriculture is unsuited, uneconomic, or impractical. In the United States, it has been stated that cow-calf enterprises are usually the residual users of range and pasture land where the only other economic alternatives are wildlife and recreation (McGrann and Parker, 1999). Systems of husbandry and management differ throughout the world, posing difficulties in defining practical herd health programs that are universally applicable. However, commonalities imposed by behavior, physiology, and ontogeny allow a generic framework to be established on which health and production principles can be imposed.

BEEF CATTLE INDUSTRY

Although the beef industry is often considered to be a single, homogenous entity, in reality it is a multifaceted industry containing a number of segments that, at times, have differing perspectives. Thus, in the United States such segments as cow-calf (both commercial and purebred), stocker, feedlot, processor, retail, and consumer can be differentiated. Smaller, more specialized segments also exist. This chapter concentrates primarily on the cow-calf, or breeding, segment of the industry, with particular emphasis on North America.

Throughout the world, and also in North America, great variation exists in beef cattle breeding operations in terms of management, environmental setting, degree of intensification (and capitalization), types of cattle used, productivity, and profitability. Not surprisingly, great variation also occurs in those health and production programs that are used. In the United States, the U.S. Department of Agriculture (USDA) has conducted a series of surveys of different animal industries under the banner of the National Animal Health Monitoring System (NAHMS). For the cow-calf sector the relevant portions occur within the Cow/Calf Health and Productivity Audit (CHAPA). Reference will be made to these surveys throughout this chapter.

As of January 1, 2000, there were 33.5 million beef cows in the United States, which represents approximately one third of the total cattle inventory (USDA Agricultural Statistics, 2000). States with the most cows were, in descending order, Texas (5.4 million), Missouri (2.1 million), Oklahoma (1.9 million), Nebraska (1.9 million), South Dakota (1.7 million), and Montana (1.6 million). In terms of individual operation size, these cows were distributed in 1996 as shown in Table 13-1.

It is apparent that the vast majority of beef cattle operations in the United States are modest in size and most probably incapable of providing the sole means of family support. In the late 1980s approximately 90% of beef farms were estimated to be owned by individuals or families (Wise, 1987), with 40% of beef farmers reporting their principal occupation as farming (compared with 93% of dairy farmers). Changes in the beef industry include a trend toward increasing herd sizes and a separation of ownership and management. Other changes include a trend toward vertical integration of different industry segments and greater use of databases and records. With the latter, on-farm computer use doubled from 1993 to 1997 (4.7% to 9.5%), while hand-written records also increased over that period (65.2% to 80.0%) (NAHMS, 1998b).

Types of operation vary from those that are economically viable, with no other farming activity except perhaps feed crop production, to those in which most of the income is derived from the sale of weaned beef calves. Such operations are usually characterized by good animal and economic management and good record keeping. Owners are often innovators and early adopters and are aware of animal health and production management services provided by veterinarians; owners request cost-effective herd health services.

A second type of operation may be represented as mixed, in which cattle share priorities with other enterprises such as cereal grain or corn production, cash cropping, grass and seed production, hay production, and sheep production. The other farm enterprises often mandate that beef cattle work share precedence in priorities such as allocation of resources and scheduling. These producers may be industrious, educated, and opportunistic and have excellent records and

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TABLE 13-1

Distribution of U.S. Beef Operations and Cow Inventories

Herd Size	1-49	50-99	100-499	500+
Operations	79.8%	11.9%	7.7%	0.6%
Cows	30.8%	19.5%	35.7%	14.0%

From National Animal Health Monitoring System: *Beef '97: Part IV: Changes in the U.S. cow-calf industry 1993-1997*, Fort Collins, Colo, 1998, U.S. Department of Agriculture.

facilities. At the other end of the scale, mixed enterprises may be represented by poorly efficient operations in which owners appear to have little control over events. Working with mixed enterprises requires an appreciation of the entire enterprise and not just the cattle component. In many parts of the world, such operations may be entirely pasture dependent for livestock, including year-round grazing, perhaps with prepared feed supplementation when required. In temperate zones, large amounts of hay must often be prepared, being fed for 2 to 6 months during the winter season.

Some beef cattle producers operate on a low-input, low-output basis. This may reflect realistic business principles for their region (as with parts of Northern Australia), a way of life that is resistant to change, or conflicting priorities. Here there may not be a recognizable breeding season, and there is often little monitoring of breeding or calving. Calves may be "harvested" at times that reflect suitable environmental conditions or convenience, or when some cash flow is necessary. Improvement of the production traits within the herd by input of good genetic material may not be a high priority for some producers. For many, their priorities are for more basic managerial inputs than for implementation of sophisticated herd-health programs or for exploitation of new reproductive technologies (Henderson, 1998). They also do not want to increase their management effort in the operation unless there is a demonstrable payoff in economic returns. In comparison with the United States, beef cattle production systems in countries such as Australia, Argentina, Uruguay, and Brazil are overwhelmingly based on pastures and likely to remain that way for the foreseeable future, despite increased use of improved pastures.

An important and influential segment of the industry consists of purebred beef cattle farms whose sole objective is to produce pureblood, pedigreed breeding stock for show and sale. Some of these are economically viable, based on cattle sales, but some are not and are subsidized by other enterprises of the farm, such as grain farming or commercial cattle production. The profitability of such operations is associated with overall industry profitability as well as marketing skills. Some of these producers have adopted high technology and are heavily involved with embryo transfer and related technologies. Many are interested in a complete animal health and production management service because of the high value of purebred breeding stock and their germ plasm.

The large number of small herds in the United States indicates that many cattle owners are reliant on other sources of income for economic survival. Many farms have cattle as an adjunct to income generators such as grain farming, oil wells, potato farming, schoolbus driving, or working off the farm. Profitability and programmatic commitment vary with size of operation, location, and motivation. Many small producers come from a farm background and live in a rural setting either by choice or by circumstance.

With such variations in the economic viability of commercial beef herds, a decision should be made as to the feasibility of adding the "costs" of a herd health program to existing costs on a beef farm. This decision is not necessarily related to size or production level. Other factors are important, including the awareness, motivation, resources, and priorities of the owner. The first step is to identify those procedures ("marketable skills") or products that can be identified as a sound investment, rather than as a cost. Here, it is assumed that emergency services are generally provided as well as standard components of preventive medicine relevant to most farms (e.g., regulatory disease testing and vaccination, basic vaccination against clostridial and perhaps other diseases, treatment for endoparasites and ectoparasites), with perhaps pregnancy diagnosis and other routine elective procedures. With such simple veterinary services, there is usually little attempt to accurately assess herd productivity or the financial impact of disease control.

A 1986 survey of the U.S. market for food animal veterinary services provided some relevant information concerning the relationship between farm characteristics and veterinary services provided (Wise, 1987). Here, the median annual sales from beef farms was estimated to be about $29,000, with median annual animal health expenditures by producers being approximately $500. Of this, 35% was spent on professional veterinary services and 65% on animal health products. Larger livestock farms and ranches spent proportionately (per animal) more on animal health products and less on animal health services than did smaller operations. In addition, larger livestock operations spent proportionately less of their animal health dollar with the veterinarian than smaller livestock operations. In this survey, producers perceived private veterinary practitioners as strong in their knowledge of diagnosis and treatment of sickness and injury and of reproduction and breeding, relative to themselves and other suppliers of animal health information. At least 7 in 10 producers would contact the veterinarian first for diagnosis and treatment of sickness or injury, 5 in 10 would contact the veterinarian first for a reproductive problem, about 3 in 10 would contact the veterinarian first for a herd management problem, and 1 in 10 would contact the veterinarian for a question on feed and nutrition. In the areas of animal and herd management and of feed and nutrition, veterinarians were thought to possess about the same level of knowledge as the producer and slightly less knowledge of feed and nutrition as feed salespersons. The veterinarians' knowledge of agribusiness and economics was perceived as weak compared with that of the producer and agricultural extension agent.

A more recent survey reinforces the previous positive perception of veterinarians as experts in matters of animal health, with signs of encouraging improvement in production areas as well (NAHMS, 1994a). Here, producers placed

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veterinarians in first position as sources of information for both animal health and beef production information, and in second position (to personal knowledge and education) as a source of nutritional information. This indicates that education, perception, and need have combined to improve the capabilities and contributions of veterinarians in wider aspects of cow-calf production than health matters alone, at least in the United States. The challenge remains for veterinarians to be remunerated adequately for their advice in these areas.

ANNUAL BEEF COW CYCLE

In a generic beef breeding herd, cows are bred naturally by bulls within a pasture or range environment. Calves are usually born in spring and nurse for 6 to 8 months before being weaned. Although principles for optimum beef production suggest that cows calve annually, constraints on this goal may be imposed by genetic and environmental interactions with normal physiological events. Diseases such as vibriosis or trichomonosis also may influence the annual beef cow cycle. However, a general aim is for heifer replacements to be bred at approximately 15 months of age and to calve as 2-year olds. Females that are already in the herd and have had calves in previous years are bred about 60 days after calving. For optimum efficiency, it is necessary to breed the heifers and cows over a period of 42 to 60 days in order to have a short calving period (span) and a concentrated calving pattern (a high percentage of calves born in the first 21 days of the calving period). Such a schedule is integral to any plan that aims to obtain a calf from each breeding female each year. Weaned calves may be sent to a feedlot to be fed for several months until slaughter as finished beef, or they may be placed in a feeder-stocker system for a period before being placed in a feedlot (or on pasture) for the "finishing" process that might take 3 to 6 months in different systems. Some heifer and bull calves are usually selected as potential breeding stock and placed on diets that provide for the optimum growth required for heifer replacements and breeding bulls. Thus the length of time from conception to finished beef requires up to 24 months, and from conception through the birth of another calf up to 42 months. This long intergeneration interval represents a disadvantage compared with other animal production systems, and it provides an incentive for improved efficiency of production in cattle.

Characterization of typical beef practices in Colorado herds was obtained from a study of management practices and their association with disease rates (Wittum et al, 1990). Here, most herds used crossbreeding, with two thirds using a breeding season of 90 days (range 60 to 365 days). Breeding soundness examinations of bulls were conducted by 35% of producers before each breeding season, whereas 42% performed breeding soundness evaluations on "new" bulls only. Pregnancy examinations were performed in 70% of herds. Most herds calved in the late winter and spring of the year. For newborn calves the most common management procedures were application of identification tags, dipping of the navel with iodine, and measurement of birth weight. Most producers gathered their cattle in the spring or early summer for branding, at which time they also castrated the male calves, dehorned the calves, and vaccinated them with a clostridial vaccine, whereas 50% of the producers implanted the calves with a growth promoter. Calves were weaned in these herds in September to November. Individual or group weights were determined on calves at weaning in 60% of herds. Other common management practices at weaning included vaccination for common viral diseases (infectious bovine rhinotracheitis [IBR], parainfluenza 3 [PI3], bovine virus diarrhea, and bovine respiratory syncytial virus [BRSV]) and treatment for internal and external parasites. The incidence and mortality rates resulting from enteric disease were higher in herds in which calves were not routinely handled immediately after birth compared with herds that did handle them at this time for routine procedures.

The disease problems that exist with extensive beef operations, such as those in Northern Australia, are varied, but the major epidemic diseases such as brucellosis, tuberculosis, and perhaps campylobacteriosis are likely reduced to low levels or almost eradicated. This is, however, not true of all diseases. For example, foot and mouth disease (FMD) is still endemic in parts of the world. Major problems include seasonally poor nutrition, low stocking rates, isolation from facilities, resources and markets, inadequate transport, large land areas, and poor records. Related problems include poor and unreliable reproductive rates, variable calf crops and greater selection emphasis on survival than on production traits. Disease entities vary with region, but trichomonosis is often endemic and external parasites may represent a large concern; micronutrient and mineral deficiencies may cause primary or secondary problems (as with the relationship between phosphorous deficiency and botulism in Northern Australia). Internal parasites tend to become less problematic as stocking rates decrease, although this can change whenever animals are forced to congregate.

"GOOD" COW-CALF PRODUCTION PRINCIPLES

A number of managerial practices are known to increase productivity within cow-calf herds when they are able to be implemented practically. These practices are mostly associated with the reproductive process, since improvements in herd fertility are considered to offer more potential for increased profitability in cow-calf operations than production traits (Wiltbank, 1994). Most indexes currently used to evaluate herd performance are related to reproductive efficiency, such as pregnancy rate, calving percentage, calving distribution, and percent calf crop. All of these affect pounds of calf produced per exposed female (Engelken, 1997). In turn, practices that have been shown to be of most advantage to herd reproduction include those in Box 13-1.

In addition, a number of other management practices associated with increased beef herd profitability in Kansas were identified by Engelken et al (1991) as follows: use of partial budgeting, fly control, use of growth promotants and creep feeding in calves, precalving parasite control in cows, and improved calf management.

BOX 13-1

Managerial Practices that Increase Cow-Calf Productivity

Restricted breeding season
"Optimum" calving season
Breeding season evaluation
Good heifer replacement program
Proper nutrition
Good herd health
Prior bull evaluation
Crossbreeding
Good records

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A number of these recommendations have been incorporated into different "packages" (Withers, 1984; Anderson et al, 1986; Prince et al, 1987), which have generally been shown to be cost effective. However, although the benefits of such proven management tools to increase herd productivity and profitability may appear to be evident, many producers are not taking advantage of them. In fact the low level of utilization of such knowledge has been identified as the most important constraint to the productivity of the U.S. beef cow-calf industry (Wikse et al, 1998). This perhaps explains why the weaning rate of calves has remained virtually static in the United States over the past several decades (Williams, 1990; USDA Agricultural Statistics, [available at http://usda.mannlib.cornell.edu/usda/reports/general/sb/b9530199.txt]).

A relative lack of adoption of "good" management principles is also evident from surveys in Ontario, Canada. Here, approximately 50% of producers did not use a specified breeding season. Of those who claimed to have a specified breeding season, only 24% restricted it to less than 90 days (McDermott et al, 1989). Approximately 12% of producers bred heifers earlier than cows, and only 30% of heifers and cows were checked for pregnancy. An earlier mail survey of reproductive efficiency and calf survival in Ontario beef cow-calf herds revealed mean losses of approximately 18% from breeding until calves were 4 weeks of age (Rogers et al, 1985). Veterinary involvement was low for recommended basic herd health procedures, with only 12% of the herds undergoing pregnancy examinations, 10% bull breeding soundness examinations, and 5% bull scrotal circumference (SC) measurement. A survey of health, productivity, and management of calves in Ontario beef cow-calf herds showed preweaning losses of about 7% (Alves et al, 1989), with 85% of this loss occurring from birth to 4 weeks of age.

In Texas, an integrated resource management (IRM) program survey revealed a relatively poor adoption rate of proven, and recommended, reproductive management principles (Williams, 1990). Here, 24.5% of producers used a controlled breeding season, 22.6% checked pregnancy, 20.8% conducted annual bull breeding soundness evaluations, 13% used artificial insemination (AI), and 7.8% used estrus synchronization methods. However, a more recent survey of successful Texas ranchers indicated a higher adoption rate of good management principles, with 75% having a defined calving season, 76% pregnancy-checking cows, and 53% using cow body condition scores (BCSs). This was considered to illustrate a positive association between adoption of such principles and profitable ranching (Wikse et al, 1998).

Data from a wide variety of U.S. locations reveal disappointing adoption rates of many proven management principles (NAHMS, 1994a, 1998a,b). In 1993, 47 percent of operations removed bulls from the breeding herd—a practice that increased with herd size to 92.8% of herds with 300 or more cows. Approximately half of the operations performed a semen test on newly purchased, leased, or borrowed bulls, whereas only 17% to 18% used this test on other bulls before the breeding season. Other data from the 1993 survey showed that nearly 18% of operations performed pregnancy testing on cows, and approximately 16% performed it on heifers. BCS was used with cows and heifers on 5.5% and 4.6% of operations, respectively, and the equivalent usage of body weight monitoring was 1.9% and 7.9%, respectively. The use of AI in beef herds remained relatively static (5% to 6%) between the two surveys.

The reasons for such relatively low adoption rates are probably many and complex. Beef producers tend to be conservative, with reasoning often based on previous experiences or hearsay. Regional differences in outlook, social pressures, and economics also occur, as well as the fact that many cow-calf producers, at least in the United States, are relatively small, are part time, or have mixed enterprises in which cattle have to share priorities. Despite such considerations, veterinarians should be in a unique position to convince clients to adopt cost-effective managerial changes and to assist clients to implement these changes. This is because no other professional has such regular and close involvement with many cattle operations, both small and large, and because veterinarians are regarded as the best single source of relevant information (NAHMS, 1994a). Encouraging results are being reported from collaborative educational programs for producers, such as one in Texas in which veterinarians, extension agents, and a major pharmaceutical company have combined forces (Wikse et al, 1998). The reasons for implementing a number of these practices are discussed below.

RESTRICTED BREEDING

In general any beef production system that requires animals to be grouped for managerial purposes such as weaning, vaccination, and marketing benefit from some form of restricted breeding season. Here, to some degree, nature imposes its own prerogatives such that, even in feral herds, a considerable degree of seasonality occurs with both breeding and calving (Spitzer, 1986). Thus, in most regions of the world, there is an "optimum" period for females to calve, suckle, and rebreed. This period is mostly related to nutritional opportunity, with other environmental factors such as heat stress and parasite populations also playing roles in different parts of the world. Producers have traditionally aimed for females to calve at this optimum period, since they tend to breed back faster, and their calves grow better, than those that calve at less opportune times. It is recognized that in some parts of the world such as northern Australia, the level of managerial inputs required to implement a severely curtailed breeding season would be uneconomic as well as logistically difficult. However, where restricted breeding seasons are feasible, their implementation is a major factor in achieving optimum production levels. Arguments in favor of restricted breeding seasons (<80 days) are given in Box 13-2.

The combination of the advantages just described has been estimated to provide an increased return of $50/cow, based on 1995 prices (Toombs, 1996). In the United States, surveys show that most calves (64%) are born within a 3-month period (February, March, April) in the spring (NAHMS, 1998b). If January and May are included, this figure rises to 80%. This reflects a breeding season that occurs

BOX 13-2

Advantages of a Restricted Breeding Season for Beef Cattle Breeding Herds

- Enhanced production potential
- Opportunity to work in concert with favorable environmental factors
- More homogeneous calf crop
- Opportunity to perform prebreeding management procedures
- Concentrated calving season
- Opportunity for strategic nutrition and improved monitoring
- Early problem detection (using herd pregnancy diagnosis and breeding season evaluation)
- Improved female replacement program
- Programmed herd health management
- Improved culling procedures

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predominantly in late spring and early summer. Despite this, indications are that breeding seasons of more than 5 months increased from 1992-1993 to 1997; there was no month in which less than 10% of operations had calves born (NAHMS, 1998b).

Although the figures indicate room for considerable improvement, it should not be assumed that the adoption of a severely restricted breeding season is advantageous in all situations and environments (Box 13-3). In a Nebraska study, comparison of breeding season lengths for crossbred females of 30, 45, and 70 days found that the highest productivity occurred with the longer breeding season (Deutscher et al, 1990). In a number of situations, very short breeding seasons produce unacceptably low calving rates (Larsen et al, 1994). The reasons for this include the extra pressure that such systems impose on normal physiologic events. For example, a generic, British-breed beef female will be pregnant for approximately 284 days, leaving 81 days to recycle and breed. However, even if she has no problems at parturition and her nutrition is good, she will still undergo delayed return to cyclicity (45 to 70 days). Thus if postpartum return to cyclicity is 40 days, the generic female will have 41 days of cyclicity to become pregnant. This translates to two to three estrus periods. Assuming that the bull (or bull battery) is fertile and sexually active, it is a reasonable assumption that she will have an approximately 60% chance of pregnancy at each estrus. Thus her chance of becoming pregnant in time to fulfill a 12-month calving interval is either 84% (two cycles) or 94% (three cycles). The variable period of anestrus following parturition is recognized as a major influence on the proportion of females that conceive during the breeding season (Wiltbank et al, 1961). Greater constraints are often imposed on this system in tropical and subtropical environments, as genotype-environmental interactions tend to cause delayed postpartum return to estrus (Chenoweth, 1994a). The result is that producers in such areas often adjust by using extended breeding seasons.

Thus calving rate may be influenced by breeding season length through three important parameters; postpartum return to estrus (PRE), conception rate per estrus exposed (CR), and gestation length (GL). The latter is influenced by calf sex (with male calves generally remaining in utero for several days longer than female calves). However, it may also be significantly affected by genotype with variation among breed-types being up to 19 days (Larsen et al, 1994). The extra gestation duration required by some breed-types necessarily reduces their postpartum period of opportunity to get pregnant within a 12-month calving schedule. Larsen et al (1994), using computer models derived from data obtained at USDA-STARS (Brooksville, Fla.) found that a decrease in the length of the breeding season does not necessarily increase calf crop and profitability. Here, models showed that when conception rate was 60% and the breeding season was 60 days, calving percentage was significantly affected by both gestation length and PRE. Variation of breeding season length (30 to 190 days) at different combinations of GLE and PRE at the same conception rate showed that even very long breeding seasons could not fully compensate for situations in which both GLE and PRE were extended. Amer et al (1996) showed that, under British systems for beef suckler herds, increasing gestation length imposed appreciable economic costs.

Moving cattle breeding operations from an extended breeding season to a restricted one can present a real challenge. If the move is made too quickly, a severe drop in production may result. Associated changes in culling patterns can alter herd dynamics with the result that it may take years for optimum production levels to be established. Prior consultation with clients should include such information. Use of computer generated "what-if" scenarios (e.g., as with DECI) is very useful in mapping different strategies and predicting outcomes, although their value is dependent on the accuracy of the "models" used. A relatively safe strategy is to reduce the bull presence in the herd in increments over a number of years so that the desired breeding season is achieved gradually. At the same time, late-bred females should be steadily removed from the female herd while emphasis is placed on getting heifers into a restricted breeding format (e.g., with estrus synchronization). For year-round breeding herds the initial strategy should be to first remove bulls during the period when experience and records indicate that little breeding activity occurs. This period of bull removal can then be extended gradually.

BOX 13-3

Possible Disadvantages of a Restricted Breeding Season

- Lost production can accompany the move to a shorter breeding season
- Difficulties can occur in coordinating calendar and season
- Closer monitoring usually required
- Good herd health becomes more important
- Late calvers, if not culled, will often miss years
- Breed and environmental differences occur in implementation

STRATEGIC PREGNANCY TESTING

Pregnancy testing should be regarded as an essential management tool in beef herds. As a technique, it represents an important "marketable skill" (Chenoweth, 1989) that allows veterinarians to gain access and credibility with cow-calf operations. However, for most effective utilization, it should be much more than a simple sorting exercise of female cattle into pregnant and nonpregnant groups. The addition of "value-added" information such as projected calving dates and patterns (as described below) makes this service more attractive (Toombs, 1996). The herd pregnancy diagnosis (HPD) represents an important starting point for beef herd diagnostics and advice, and it is a pivotal component for informed managerial decision making (Box 13-4).

For this information to be used most effectively, we need to be able to determine the distribution of pregnancies within the herd and its subgroups and to compare these with expected and actual herd averages. Analysis of this data will help to determine whether or not a problem exists and, if so, what might be the cause. In many cases this analysis will also help to indicate what needs to be done to specifically identify and rectify the problem and with which group(s). A description of such analyses is given in the discussion on breeding season evaluation later in this chapter.

When used in conjunction with a restricted breeding season, the HPD is best done relatively early after bull removal (6 to 8 weeks) but late enough so that early pregnancies are not missed. The most common method used by veterinarians to perform this task is transrectal palpation of the female reproductive tract; this technique has been well described elsewhere (BonDurant, 1986; Anon, 1998). With this method, greatest accuracy in aging the conceptus occurs between days 35 and 65, with precision being reduced as gestation proceeds. In this chapter, methodology is not presented because it is covered adequately elsewhere (Anon,

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BOX 13-4

Advantages of Herd Pregnancy Diagnosis

Identification of pregnant and nonpregnant animals
Analysis of group patterns for problem solving ("breeding season evaluation")
Sorting of animals into groups for specific purposes (e.g., strategic feeding, calving supervision, culling, or rebreeding)
Selection of replacement females
Culling for infertility*
Identification and treatment of other problems†

*Culling options vary; however, priority should be given to culling nonpregnant and "late" cows.
†For example, cancer eye treatment; a procedure that can add considerably to the value of cull cows and extend the useful life of others in the herd.

BOX 13-5

Information for Breeding Season Evaluation of the Beef Herd

Breeding herd inventory
Sires used
Pastures
Bull-to-female ratios
Breeding season dates
Pregnancy rates (overall, and per 21-day breeding period)
Expected calving dates and distribution
Herd averages (and variation)
Female factors
Age-parity
Breed
Body weight
Frame score
Body condition
Lactation status ("wet" or "dry")

From Traffas V, Engelken TJ: Breeding season evaluation in beef herds. In Howard JH, Smith RA, editors: *Current veterinary therapy 4, food animal practice*, Philadelphia, 1999, WB Saunders.

1998). However, it is of value to emphasize the importance of good working facilities (Grandin, 1993; Anon, 1998) that help to safeguard both the operator and animal and that facilitate accurate results. In addition, awareness of the biomechanical principles involved with this task (Anon, 1998) can help to prevent chronic injuries to palpators. The Australian Association of Cattle Veterinarians (AACV) has instituted a national accreditation scheme for cattle pregnancy diagnosis based on transrectal palpation (Anon, 1998). The objective of this scheme was to promote excellence in the skills of pregnancy testing and to introduce a system of accountability. With the latter consideration, accredited veterinarians are issued with plastic, wrap-around tail tags that are used to identify four classes of cattle as they are being tested. The categories represented are NDP (not detectably pregnant), CATA (open, or up to 3 months pregnant; this tag only used in Victoria, and it indicates category "A"), U4 (up to 4 months pregnant), and O4 (more than 4 months pregnant). Each tag has an individual animal number as well as the accreditation number issued to that veterinarian. In addition, the tag is identified as being issued by the Australian Veterinary Association. Procedures exist for the orderly handling of complaints. In addition the AACV has issued welfare guidelines for the use of cattle in pregnancy-testing schools.

Other methods in addition to transrectal palpation are available for pregnancy diagnosis in cattle. Tests of blood or milk progesterone levels can differentiate between a pregnant animal and one that is in proestrus or estrus (Anon, 1998). This method is more accurate for detecting "open" females (90%) than in correctly diagnosing pregnancies (32% to 34%). Since accurate breeding dates are necessary for best use of this method, it has most application in conjunction with AI programs, and more with dairy cattle operations than with beef cattle.

Ultrasonography—particularly that which uses real-time, B-mode technology—has shown rapid development and acceptance for pregnancy diagnosis within the beef industry. Ultrasound has advantages beyond those of transrectal palpation. These include the ability to accurately (and conclusively) diagnose early pregnancies (before Day 30), to determine fetal sex (after Day 55), and to help diagnose problems in the female reproductive tract. In addition, ultrasound can assess fetal viability through heartbeat, and the operator is less apt to "miss" detecting twin fetii than with transrectal palpation. Ultrasound images of actual pregnancies can also be useful as a marketing tool for purebred and specialty cattle operations. On the distaff side the equipment is expensive (although price per features is steadily reducing), it is susceptible to damage, and extra training is necessary for proficiency to be obtained.

Breeding Season Evaluation

Breeding season evaluation is a tool for assessing the reproductive performance of the cow herd (Spire, 1986). It includes obtaining relevant information, its analysis and interpretation, and recommendations for improvement. Here, reproductive performance is recognized as a factorial, influenced by many factors including sire fertility, herd health aspects, and female opportunity. One measure of reproductive performance is the number of exposed females that actually raise a live calf. Other valuable information may be obtained from an analysis of the distribution of pregnancies (and calvings) that resulted from particular breeding season (Mossman and Hanly, 1977). This distribution may be studied on the basis of timing (e.g., 21-day estrus periods), breeding groups, female age or parity, nutritional opportunity (e.g., BCS), or any other identifiable category. Such analyses provide the basis for evaluation of either the breeding or calving season (Mossman and Hanly, 1977; Traffas and Engelken, 1999). For evaluation of the breeding season, good records should be obtained at the time of pregnancy testing for the subsequent analysis to be valid. Useful information for this task is found in Box 13-5.

The interpretation of pregnancy (or calving) patterns may be illustrated with reference to three herd patterns (Table 13-2 and Fig. 13-1).

In this diagrammatic representation of the breeding performance of three herds, all herds ultimately achieve the same percentage of pregnant females (95%). However, differences in the path taken to achieve this result cause

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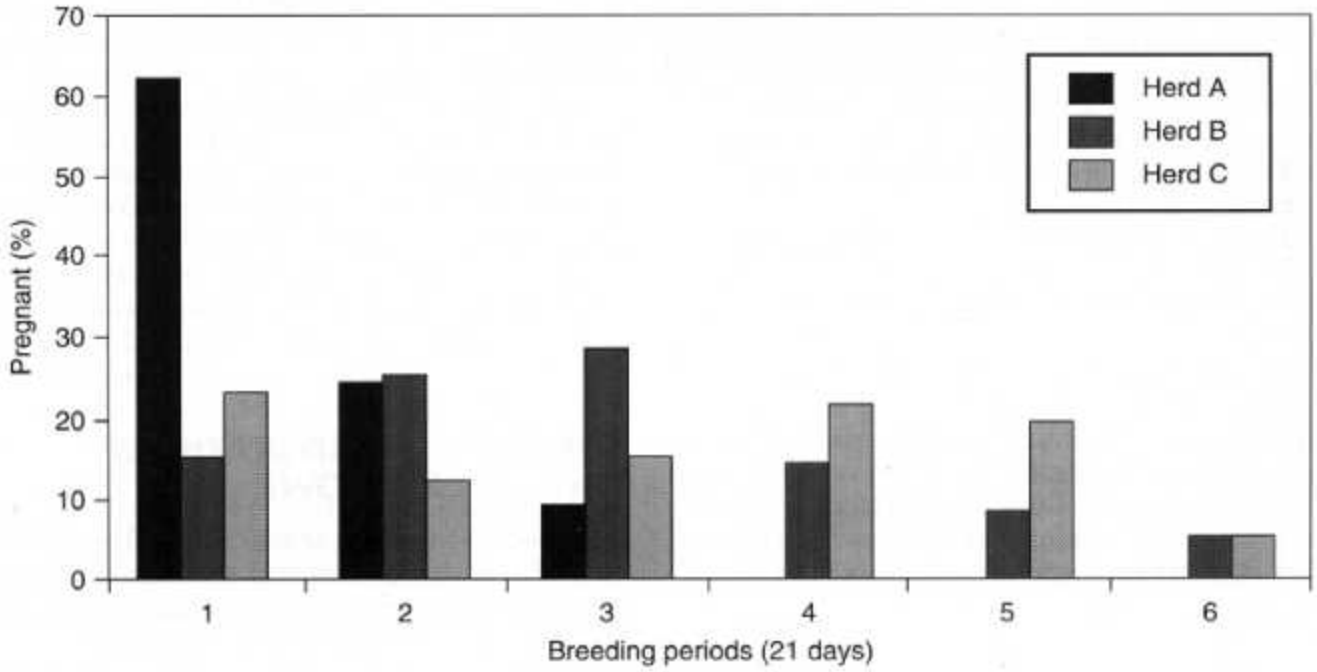

FIG. 13-1 Pregnancy patterns in three different herds per 21-day breeding period.

TABLE 13-2

Hypothetical Pregnancy Patterns per 21-Day Breeding Period in Three Herds

Periods	Herd A Pregnancy (%)	Herd B Pregnancy (%)	Herd C Pregnancy (%)
1st 21 Days (0-21)	62	15	23
2nd 21 Days (22-42)	24	25	12
3rd 21 Days (43-63)	9	28	15
4th 21 Days (64-84)	—	14	21
5th 21 Days (85-105)	—	8	19
6th 21 Days (106-126)	—	5	5

considerable difference in economic returns and provide valuable diagnostic clues.

Herd A

The pattern of pregnancies occurring with herd A—62%, 24%, and 9% of pregnancies occurring in the first, second, and third, 21-day period of the breeding season, respectively—is optimum. This is representative of all females cycling at the beginning of breeding, fertile bulls, and a conception rate (i.e., one cycle pregnancy rate) of approximately 60%.

Herd B

Herd B illustrates a problem of delayed, and perhaps inconsistent, conceptions. Delayed conception may occur for several reasons, as follows:

Females Were Not Cycling at the Start of Breeding. A common cause of delayed conception is lack of sufficient time postpartum for females to resume cyclicity, or a situation that is often compounded by interactions between growth and lactation demands and suckling stimuli. Beef cows often reach peak lactation between 6 and 8 weeks' postpartum. Younger females, particularly first-calf heifers, require longer postpartum intervals (PPIs) than do older, multiparous females. Some breed types (e.g., those of *Bos indicus* heritage) require longer PPIs than others. Female parity, calving dates, size and state of udders, and size of calves all provide valuable clues in relation to possible causes.

Inadequate Nutrition. The Herd B pattern may be encountered when nutrition is inadequate, although continuation of this problem would probably lead to lower final pregnancy rates than those shown in Table 13-2. If nutrition is a problem, BCS should provide valuable insights. Even though some months may have elapsed since breeding, important relationships between pregnancy status and BCS should still exist. Pasture differences may be evident, although strong BCS relationships should be evident here as well.

Bull Infertility. Another possible cause of delayed conception in the herd is use of subfertile bulls. Here, the final pregnancy rate would most likely also be depressed. Bull problems are usually identified with a specific breeding group and cause nonpregnancy or late pregnancy in females that should have been otherwise cycling and "eligible." This

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problem may well have been avoided with a breeding soundness evaluation of the bull team before the breeding season, especially if libido or serving capacity testing had also been conducted. Without that information, and assuming that bulls are not obviously lame or otherwise defective, veterinarians should conduct appropriate tests to rule out a bull fertility problem.

Infertility Disease. The Herd B pattern may also occur with infertility diseases such as vibriosis or trichomonosis, although this would not represent a typical pattern for these diseases when introduced into a naive female population. However, if the population contains a mixture of females of differing susceptibility to either of these diseases, then patterns such as this may occur. Again, lower final pregnancy rates than shown in this example could be expected. If the cause of this pattern is not readily apparent from the preceding considerations, and especially in the absence of vaccinal history, then the appropriate disease tests should be conducted.

Herd C

Herd C shows strung-out conceptions that lack a consistent pattern. This is more suggestive of infertility disease than the Herd B scenario, although lower final pregnancy rates again might be expected. Elimination of possible causes such as PPI (very young calves at foot), nutrition (BCS), and bull infertility would strengthen this supposition.

COST OF DELAYED CALVING

An economic estimate may be made of the effects of delayed calvings based on calf weaning weights and growth rates, and the price paid for calves. In the examples in Table 13-3, which are based on the three example herds from Fig. 13-1, the average weaning weight for calves born in the first 21 days of calving is assumed to be 500 lb (227 kg). If calves were born at an average weight of 80 lb (36 kg), then growth from birth to weaning (at approximately 7 months) averages approximately 2 lb (0.9 kg)/day. A calf price of 80 cents/lb is used in this example. Cow herds consist of 100 females, with ultimate pregnancy rates being similar (95%) for all herds.

The difference in calf receipts between an optimum calving season stretched over 63 days, and an extended one stretching over twice that period, was as great as $7500 in this example (Table 13-3) using 100 cow herds. For a 1000-cow herd the difference could be as great as $75,000. Managerial remedies for extended and erratic calving patterns are available, as discussed elsewhere in this chapter. The costs of these remedies need to be weighed against the losses estimated above.

GENETIC CONSIDERATIONS (THE "IDEAL" COW)

Selection of breeding females must be made within the context of environmental and managerial constraints, market dictates, economic realities, and conflicting priorities. Although such considerations imply that a certain degree of flexibility is necessary, it is apparent that many beef females are not productive. Bellows and Short (1994) reported that failure of cows to become pregnant was the largest single factor contributing to lowered calf crop.

Consideration of the attributes of the "ideal" cow is influenced by a number of factors, some of which might reasonably be expected to differ with region. However, Box 13-6 includes important traits for most environments.

Selection and maintenance of such traits in the cow herd requires good records and strict attention to a good replacement heifer program. Production and reproduction traits do not always go hand in hand, so it becomes a challenge for females to excel in all requirements. An ideal breeding system would allow some separation of lines that emphasize reproductive and maternal traits in breeding females from production traits of terminal offspring, as practiced in the swine industry. It is also difficult for a given genotype to excel in all environments, with this consideration being particularly relevant for temperate breeds raised in subtropical or tropical environments (Hauser, 1994).

TABLE 13-3

Effect of Calving Distribution on Calf Weaning Weights and Returns

Calving Period	Average Calf Weight (lb)	Herd A: Total Calf Weaning Weight (lb)	Herd B: Total Calf Weaning Weight (lb)	Herd C: Total Calf Weaning Weight (lb)
1	500	31,000	7,500	11,500
2	458	10,992	11,450	5496
3	416	3744	11,648	6240
4	374	—	5236	7854
5	332	—	2656	6308
6	290	—	1450	1450
Total lb weaned	—	45,736	39,940	38,848
Estimated returns (at 80 cents/lb)	—	$38,589	$31,952	$31,078

Herds A , B, and C consist of 100 cows..

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In general, published results suggest that the heritability of cattle fertility in cattle is low (Bellows and Staigmiller, 1994), although this should not lead to the conclusion that the genetic component of fertility is small (Table 13-4).

Fertility is poorly defined and measured in cattle. It is a complex trait, with contributions from both male and female factors. Genotype-environmental interactions further obscure the issue, with some evidence that selection for fertility, at least in females, might be more rewarding in stressful environments (Deese and Koger, 1967). Despite these considerations, it is clear that selection against low fertility or infertility in cattle breeding herds is both important and rewarding (Koger, 1967; Bellows and Staigmiller, 1994). This presents a major opportunity for veterinarians to work with producers to identify and remove individuals that are below herd norms or goals in terms of reproductive or productive performance and thus to raise herd performance. Such selection should include not only "open" females but those that produce substandard calves. Although females that have had dystocia problems should be culled because of lowered productivity, it is not yet clear how successful genetic selection against dystocia might be (Bellows and Staigmiller, 1994).

Despite the relatively low heritability of cattle fertility, identification and selection for certain traits associated with fertility can be advantageous. For example, as discussed below, scrotal circumference in bulls is favorably associated with sperm numbers and semen quality in bulls as well as age at puberty in related heifers.

BOX 13-6

"Ideal" Cow Traits

High fertility
Early puberty
Longevity
Low maintenance
Milk and size compatible with ranch constraints
Calving ease
Production and raising of healthy calves of required beef quality-quantity

TABLE 13-4

Heritability Estimates for Beef Cattle

Trait	Heritability (%)
Female reproduction	10-20
Mothering ability	20-25
Weaning weight	20-25
Feed conversion	30-35
Yearling weight	60-70
Mature weight	60-80
Skeletal size	60-80

From Bolze RP: Beef cow genetics that will be profitable in the future. From Cow-Calf Conference VI: Focus on Basics of Good Management, Kansas City, Mo, 1996, Kansas State University.

CROSSBREEDING

No single breed has all of the characteristics to excel in all beef production traits in all environments. Further, traits that are important for reproduction are not necessarily those that are equally important for production. One example is calf birth weight, which is related favorably to other aspects of growth but leads to dystocia, and subsequent rebreeding problems, in the dam (Laster and Gregory, 1973).

Heterosis has been shown to favorably influence productivity and profitability in cattle breeding enterprises by increasing the survival and growth of crossbred calves and by increasing the reproductive rate of crossbred cows and the weaning weight of their calves (Cundiff et al, 1992; Koch et al, 1994). In general, the performance of crossbreds exceeds that of either of the parental breeds, especially for composite traits such as lifetime productivity. Particular advantages in pounds of calf weaned occur with *Bos indicu-Bos taurus* crosses (Cundiff and Gregory, 1999), with this advantage being greatest in subtropical and tropical regions. Over time, two-breed rotations will retain approximately 68% of original heterosis and three-breed rotations retain 86%, whereas two-breed composites retain 50% and four-breed composites retain 75% (Cundiff and Gregory, 1999).

Complementarity is the process whereby breed types are crossed so that direct and maternal breed effects are combined with heterosis to optimize performance. This process can help match genetic potential for factors such as growth, size, reproduction, and maternal ability as well as carcass and meat characteristics with external factors such as climate, nutrition, and market preferences. Here, an example would be to use specialized male breeds as static terminal sires with crossbred females to maximize favorable, and minimize unfavorable, traits.

Important interactions occur between genotype and environment, such that it is useful to identify those biological types of cattle, or crosses, best suited for both production and market environments. Here the genetic potential for mature size (and maintenance requirements) and overall productivity should be matched with both actual environment and economic, available feed. For producers in areas such as Northern Australia and Argentina, Southern Brazil, and the United States, this often means using crosses between *Bos taurus* and *Bos indicus* breeds, which consistently outperform purebred cattle in subtropical and tropical environments (Franke, 1980).

CULL COW SELECTION AND MANAGEMENT

The identification and marketing of cull females has important economic and genetic implications for cattle breeders. Normal female replacement rates in U.S. herds vary from 10% to 20% (Engelken, 1997). This means that the sale of cull females represents a significant portion of income for many beef herds. Monitoring of the reasons for culling can shed valuable information on genetics and management within a herd, as well as possible disease conditions.

Culling of cattle in a beef operation usually implies removing those that have failed to meet or maintain performance criteria for the herd (Spire, 1997). Other reasons may include physical or temperament problems in animals as well as judicious culling during periods of environmental hardship or economic necessity (Table 13-5). Each operation has its own unique biological or economic criteria for culling animals (Spire, 1997). The identification of cull cows as a profit center provides the opportunity to develop programs that optimize cull cow management and returns. Cull animals represent an important component of farm economics, with approximately 11% of cows being sold annually for slaughter in the United States (NAHMS, 1998a).

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In the NAHMS (1998a) survey, culling patterns differed with size of operation. For example, pregnancy status (overall 25.6% of operations) increased its representation from 16.2% in operations with less than 50 females, to 69.4% in those with 300 or more females. Larger operations also put more emphasis on culling on the basis of age, physical soundness, and the production of poor calves. Some regional differences were also apparent, with less culling for pregnancy status in the south-central region, where more culling occurred on the basis of economics than in other regions. This last factor may, however, have been influenced by severe drought conditions in the south-central region of the United States during the survey period in 1996.

The judicious removal of nonperforming females is also important in maintaining or improving herd fertility, since the assumption is that these represent a subfertile group. Considerable progress can be made in improving herd fertility by regularly identifying and removing this group (Koger, 1967). However, it should be noted that the assumption that cull cows are necessarily unproductive may not always be correct, since recent surveys indicate that approximately 43% of cull cows in the United States are pregnant at the time of survey (NAHMS, 1998a). In addition, "open" females are not necessarily infertile (Neville et al, 1987). Identification of appropriate candidates for culling is critical and should be an important "value-added" component of pregnancy testing. Veterinarians have an opportunity to be more directly involved with culling decisions to ensure that these are made in the best interests of the client, especially since cull candidates are not necessarily obvious on superficial examination. Conflict might also occur between the needs of cash flow and herd improvement. However, when reproductive potential is considered, a culling decision "tree" for cows and first-calf heifers based on removal priorities can be established. Because culling often follows pregnancy testing, veterinary inputs in selection of best cull candidates are invaluable. A priority list of cull females may be established as shown in Box 13-7.

Cull cows represent a potentially valuable source of income that should be managed accordingly. Quality, food safety, and welfare issues are important, as well as those of maximizing returns from these animals. Veterinarians should play a pivotal role in ensuring that these considerations are best integrated.

ECONOMIC CONSIDERATIONS

Economic viability in cattle-breeding operations generally follows a cyclical pattern driven by supply and demand. The length of the cycle is influenced by both net reproductive rate and generation interval, which together determine how quickly herds can rebuild after prolonged periods of high slaughter rates (Holmes, 1989). A trend, which has only recently improved, has been for steady increases in costs associated with relatively static, or decreasing, returns. In the United States an estimated 90% of cow-calf producers recently did not return a profit (McGrann and Parker, 1999). This was reinforced by a standard performance analysis (SPA) survey performed in Texas (McGrann and Wilke, 1996) in which cow-calf producers were placed into quartiles based on profitability (Table 13-6). Despite similarity in a major measure of production performance (weaning percent) between groups, financial performance differed markedly. This illustrates how financial performance may be unsatisfactory, even though production appears to be satisfactory.

Profit is a term that is much misunderstood in the cow-calf industry, partly because many cow-calf operators are not attuned sufficiently to business practices. Financial profitability is defined as net return to business equity capital. As well as change in equity, measures used to assess profitability can include accrual net income, return on assets (ROA), and return on equity (ROE). The accurate estimation of profitability necessitates the use of business financial analysis through the use of accrual adjusted financial statements. The increasing acceptance of SPA in the United States is providing both financial and productive benchmarks for cow-calf operations, as well as education in the use of appropriate financial methodologies. However, to fully exploit such information, an enterprise needs to have good records of both economic and production factors. Such records are often not easily obtained, or compared, because of overlapping of production and fiscal years, resources shared with other farm activities, variation in claimed expenses and wages, and capital costs shared by different enterprises. Despite such problems, it is still im-

TABLE 13-5

Reasons for Culling Cows

Reason	Cows (%)	Operations (%)
Age or bad teeth	24.3	57.8
Pregnancy status	24.3	25.6
Economics	18.5	14.1
Bad calves	5.7	11.7
Other reproductive	2.9	8.2
Physical soundness	2.1	6.4
Udder problem	1.5	5.8
Temperament	1.3	6.4
Bad eyes	0.8	4.1
Respiratory problem	0.2	1.0
Other	2.9	5.5

From NAHMS: *Beef '97: Part 1: Reference of 1997 beef cow-calf management practices*, Fort Collins, Colo, 1997, U.S. Department of Agriculture.

BOX 13-7

Cull Female Priority List

1. Females that have had dystocia, eye cancer, or other severe problems
2. Females that have problems rearing calves (e.g., mastitis, "bottle teats")
3. Nonpregnant "dry" aged females
4. Nonpregnant "dry" younger females
5. Nonpregnant "eligible" heifers
6. Nonpregnant "wet" older females
7. Nonpregnant "wet" younger females

"Wet" females are those considered to have suckled a calf from the most recent calving season. "Dry" females are considered to have not suckled a calf during the same period.

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portant for producers to analyze the profitability of the cow-calf enterprise to ensure their long-term survival (Jones and Simms, 1997).

Profitability of a cow-calf enterprise is influenced by a number of factors, the most important being production costs, percent of cows weaning a calf, calf weaning weight, and the prices received for those calves (Jones, 1997). Production costs, herd fertility, and calf weights are amenable to on-farm management, whereas calf price may be considered unmanageable at the farm level. However, some aspects of calf price can also be influenced on farm, including genetic selection, animal sorting (for market), restricted breeding seasons, timing of sale, retained ownership, and marketing methods.

Standardized Performance Analysis

Analyses of production costs and performance measures are useful to producers because they can compare the performance of their enterprise with their own goals, as well as relative performance compared with that of benchmarks. Obviously, to improve the efficiency and profitability of an enterprise, it is first necessary to have an accurate picture of its production and economic status. However, comparison of cow-calf performance in different locations and environments requires a standardized system of evaluation. SPA is a system developed by the National Cattlemen's Association (now National Cattlemen's Beef Association), in association with the Cooperative Extension Service, to provide a standardized basis for interranch comparisons in terms of production (SPA-P) and financial (SPA-F) efficiencies, which are integrated into key performance measures. As such it represents a valuable tool for beef producers to improve efficiency and lower costs of production.

Historically, determining cost of production has proved to be a frustrating, and consequently unusual, exercise for cow-calf producers. SPA helps producers identify major costs in their operation. It should not be regarded as a record-keeping system but as a tool to improve both management and competitiveness.

A simplified, more user-friendly version of SPA is SPA-EZ, an analysis system designed to calculate the cost of production. It is based on SPA and uses the same terminology and standards. The information used for SPA-EZ can be generated from tax return data, although expenses need to be allocated to just the cow-calf enterprise.

Standardized Performance Analysis Production and Reproduction Measures

The evaluation of reproductive efficiency requires analysis over the entire production cycle, which extends from breeding to weaning of the subsequent calves. The production cycle, however, refers to a calendar 12-month period. Thus some overlap occurs, and analysis for one fiscal year may involve production records from two or even three calendar years. For example, calves born in early 2002 are included in the production cycle for that year, even though the relevant reproductive cycle commenced at the breeding season in 2001. Reproductive efficiency measures for that herd, however, apply to the year that the calves were weaned (2002), based on the number of females actually exposed in 2001.

Among the reproduction and production traits analyzed by SPA are the following: pregnancy percentage, pregnancy loss, calving percentage, calving distribution, calf death loss, calf crop or weaning percentage, actual weaning weights, weaning age, pounds weaned per exposed female, and female replacement rate. Definitions of these terms are given in Box 13-8.

Standardized Performance Analysis Financial Measures

SPA attempts to isolate the cow-calf operation from other enterprise activities to arrive at a realistic, and comparable, financial picture. The overall financial performance, and

TABLE 13-6

Cow-Calf Performance Measures Ranked by Net Income Quartiles (1991-1999)

	Quartile			
Performance Measure	**Top 25%**	**Second 25%**	**Third 25%**	**Bottom 25%**
Weaning (%)	85	84	81	81
Weaning weight (lb)	538	530	518	502
Pounds weaned per exposed female	455	441	419	410
Raised and purchased feed ($/cow)	60	82	89	106
Grazing cost ($/cow)	73	74	75	110
Net income ($/cow)				
Financial	141	35	−39	−222
Economic	28	−52	−110	−306

From McGrann J, Parker J: *Cow-calf SPA shows great opportunities for improvements*, SPA-10 in IRM Handbook, July 1995, Texas Agricultural Extension Service.

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BOX 13-8

Selected Definitions of Reproductive Performance

PREGNANCY PERCENTAGE
(No. of females diagnosed as pregnant/no. of females exposed) × 100*

PREGNANCY LOSS PERCENTAGE
(No. of females diagnosed as pregnant that fail to calve/no. of females diagnosed as pregnant) × 100†

CALVING PERCENTAGE
(No. of calves born/no. of exposed females) × 100

CALVING DISTRIBUTION
Cumulative number of calves born by 21, 42, and 63 days of the calving season, as well as those born after 63 days‡

CALF DEATH LOSS BASED ON EXPOSED FEMALES§
(No. of calves that died/No. of females exposed) × 100

CALF DEATH LOSS BASED ON CALVES BORN
(No. of calves dead/no. of live calves born) × 100

CALF CROP, OR WEANING PERCENT
(No. of calves weaned/no. of exposed females) × 100

AVERAGE WEANING WEIGHT
Total weight of weaned calves/total no. of calves weaned

POUNDS WEANED PER EXPOSED FEMALE
Total lb of calf weaned/total no. of exposed females

FEMALE REPLACEMENT RATE
([Raised replacement heifers exposed for first calf breeding + purchased replacement heifers and exposed breeding cows]/no. of exposed females) × 100

From McGrann JM, Parker J: *IRM-SPA handbook: factors influencing profitability of the cow-calf operation, SPA 50-1*, College Station, Tex, 1999, Texas Agricultural Extension Service, Texas A&M University.

*Adjustments to "exposed" female numbers are made as follows: "exposed" animals that are sold or otherwise removed between breeding and pregnancy diagnosis are subtracted; "exposed" animals purchased during that period are added. All death losses of exposed females should remain within that group.

†The numerator should include females that abort between pregnancy test and calving. Purchased pregnant females should be added to the divisor whereas pregnant females sold should be subtracted.

‡The assumption is made that the first 21-day calving period should start 285 days following introduction of bulls to the mature cow herd. If this date is unavailable, then counting starts at the time of calving of the third mature (3 years and older) cow. All calves delivered, dead or alive, are included in this analysis.

§Calf death loss should include calves lost at birth plus calves that die before weaning.

status, of any business or enterprise is evaluated with measures of parameters such as profitability, liquidity, solvency, financial efficiency, repayment capacity, and change in equity. These are all specific, meaningful terms to the financial cognoscenti. Unfortunately, they are often poorly understood within the cow-calf sector.

Liquidity indicates the capability of the enterprise to pay accounts or bills when they become due. Although a positive cash flow may provide evidence of liquidity, this does not necessarily imply profitability. Solvency assesses the ability of the enterprise to meet all financial obligations if all of its assets are sold. A useful measure of solvency is the equity:asset ratio. As previously stated, profitability is the net return to business equity capital, and it measures the financial performance of the enterprise over a period of time (usually 12 months). Investments and returns are expressed on a per unit asset basis. Thus enterprise financial "health" (or profitability) may be represented on the basis of percent return on assets (ROA). This is best described in terms of total assets associated with the enterprise. In the case of a cattle-breeding enterprise, however, it may also be expressed in terms of return per breeding female or other specific assets such as designated land area. Change in owner equity (assets minus liabilities) is probably the best single value that summarizes overall business progress (McGrann and Parker, 1999).

The financial position and economic performance standards of a cow-calf operation may be assessed on a per-cow or per-hundredweight (100-lb) weaned basis. Primary measures that are obtainable from this analysis include capital investment per cow, debt per cow, the debt-to-equity relationship, the value of feeds fed, grazing costs, nonfeed costs, capital costs, income or return on assets, and unit costs of production (e.g., cost per pound of weaned calf, per cow, or per land area).

Good records are essential for the effective conduct of any enterprise analysis. These include herd inventory records at various times in the calf production cycle, including the following: females exposed to breeding, pregnant females sold and purchased, abortions observed, twins born, open females at calving, calf deaths before weaning, and purchases of foster calves. Useful management information includes dates of breeding season, calving, and weaning, as well as weaning weights. Good records are particularly necessary for feed inputs because these usually represent a major item. These should include details of all grazing resources used (dates, land area, number of head, rental, or agistment, etc.), as well as purchased and harvested feeds. Other expenses, such as repairs, interest, fuel, and veterinary expenses, also need to be assigned to the cow-calf enterprise, as well as labor (hired and family). Records should include the purchase of breeding stock and other capital costs. Finally, all income assigned to the cow-calf herd (including calf and cull animal sales, replacements, animals transferred to other enterprises such as stocker-feeder) is used to develop an income statement (listing all income and expenses for the enterprise) and a beginning and ending balance sheet for the fiscal year.

Analysis of these records is relatively simple once the effort has been put into obtaining them. Software such as FINPACK, as well as that provided by SPA, is useful in preparing the appropriate economic and production summaries.

Table 13-7 shows how such figures can be used for comparative purposes.

On an individual enterprise level, the amount of information generated can be comprehensive. For examples, economic and production summaries for a Kansas beef herd are given in Tables 13-8 and 13-9.

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TABLE 13-7

Summary of Select Standard Performance Analysis Financial Measures in the United States (1991-1996)

INVESTMENT AND RETURNS	
Total investment per breeding cow (cost basis)*	$1708
Percent return on assets (cost basis)†	6.95%
Total investment per breeding cow (market value)	$3583
Percent return on assets (market value)	3.27%

*Cost basis: historical acquisition cost minus accumulated depreciation.
†Market value: current market value of the asset.

Analyses of Herd Performance

Such data as those just shown can provide useful information for evaluation of the performance of the cow-calf operation (Rogers et al, 1994). For example, pounds (or kilograms) weaned per exposed female is a useful estimate that combines a number of aspects of reproduction and production. These include nutrition, male and female fertility, genetics for growth and maternal traits, and loss from death and disease. The female replacement rate indicates the proportion of the female herd represented by replacement heifers and provides insight into culling strategies, cow longevity, and, possibly, genotype-environment compatibility. A high replacement rate generally means higher herd costs and lower productivity per cow, since a large proportion of the herd consists of first- and second-calf heifers (Rogers et al, 1994). The distribution of calvings by 21-day periods is also an important measure of reproductive efficiency. Since calf age is directly linked to weaning weight, more calves born earlier in the calving season will lead to heavier aggregate weaning weights. If calves grow at 2 lb (0.9 kg)/day, then a delay of one cycle will lead to a loss of 42 lb (19 kg) at weaning. If all females are cycling at the start of the breeding season, and bulls are capable, it is reasonable to expect a conception rate (one cycle pregnancy rate) of 60%. This would cause an expected distribution of pregnancies (and calvings) for 100 females, as shown in Table 13-11.

A realistic goal is for a 65% calving over the first 21 days of the calving season (Rogers et al, 1994). Variations on the normal pattern may be due to a number of reasons, including the following:

- Female infertility: lack of puberty, postpartum anestrum, nutritional deprivation, venereal disease
- Male infertility: primary bull infertility, lack of libido, social factors, venereal disease

Important clues as to patterns of pregnancy (and calving) and their causes can be obtained from analysis of HPD data.

Factors Influencing Cow-Calf Profitability

As previously observed, control of production costs is the key to profit in the cow-calf enterprise. These may be handled as follows:

1. Lower production costs while maintaining the same production level
2. Increase production while maintaining the same production costs
3. Lower both production and production costs but ensure that costs are lowered more than production
4. Increase both production and production costs but ensure that production is raised more than costs

The first step in any program to improve profitability must be identification of production costs. Although the use of SPA for this purpose has been highlighted in this chapter, there are many avenues of assistance (and programs) available from state extension services and university resources. Once production costs are identified, the contributions of different elements may be studied to locate possible areas for improvement. The influence of changes in a number of key factors based on 1995 U.S. prices is shown in Table 13-10.

A 10% change in total feed cost has a significant effect on both parameters, approximating a 5% change in weaned calf crop. Reducing feed costs by such an amount is not unreasonable, if innovative measures are taken, especially to reduce dependence on harvested and stored feeds. Veterinarians can have a great financial impact on the profitability of beef operations by formulating least cost rations for client's cattle (Toombs, 1996), with the most overlooked area for veterinarians and nutritionists alike being a cheaper feeding program over the winter months. The relative contributions of different factors to the cost of producing a calf in the United States have been estimated from SPA data. Here, approximately 65% of the total costs are attributable to feed (bought and raised feed and grazing), which indicates that this should be a major target for reducing costs. Veterinary and medical bills are relatively minor, comprising approximately 4% of variable costs. By combining NAHMS and SPA information, a number of U.S. producers were identified who reported either positive or negative net returns in 1993 (NAHMS, 1996). Here, the average size of operation (167 versus 162 cows, respectively) was very similar, indicating that size in itself was not a major influence on profitability. Positive return producers obtained a slightly higher price for their calves than did negative return producers ($87.97 versus $86.90/cwt respectively), indicating that price obtained for product was not a major determinant of profitability. The positive return group also fed less expensive feeds than did the negative return group. However, the biggest cost savings came through the amount of capital invested per cow. Those operations showing positive returns had considerably less investment per cow than did those showing negative returns ($2029 versus $3870, respectively). At a conservative interest rate of 6%, this would account for a difference of almost $26/cwt of weaned calf. Most of this extra capitalization was due to real estate. The collective differences were reflected in a lower debt per cow in the positive group than in the other ($275 versus $530, respectively), causing a further loss of $6.42/cwt of weaned calf for the group that had negative returns.

The resource base available to cattle producers will influence costs, as well as types of feed and weaning weights achieved. Here, considerable difference occurs in cow-calf production costs between different geographic and climatic regions in the United States, as shown in Table 13-12.

Economies of size have been reported (Langemeier et al, 1995), with herds of less than 500 cows having higher relative costs than those having more than 500 cows. Herds in the SPA program with less than 50 cows were considered to be losing equity.

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TABLE 13-8

Example Cow-Calf Enterprise Economic Summary

Factor	Economic ($/cow)	Cash Flow ($/cow)
Income:		
Inventory adjustment	−8.70	—
Calf sales and transfers	533.13	533.13
Asset sales (culls, equipment)	—	—
Gain of loss on assets	−2.50	—
Total	521.93	533.13
Variable costs:		
Hired labor	0.00	0.00
Repairs and maintenance	26.61	26.61
Interest paid	33.26	33.26
Purchased/harvested feed	84.15	84.15
Grazing costs	159.89	159.89
Marketing	10.37	10.37
Breeding	0.00	0.00
Taxes and insurance	4.57	4.57
Fuel, oil, and utilities	11.22	11.22
Veterinary and medical costs	14.13	14.13
Miscellaneous	0.00	0.00
Total	344.20	344.20
Return above variable costs	177.74	188.93
Fixed costs:		
Nonanimal depreciation	0.45	—
Interest charge	0.20	—
Principal payments	—	73.91
Total	0.65	73.91
Total costs	344.85	418.11
Net return to labor and management	177.09	115.02
Break-even and sales prices:		
Feed costs/hundredweight	50.98	50.98
Variable cost/hundredweight	71.91	71.91
Total cost/hundredweight	72.04	87.35
Gross return/hundredweight	109.04	111.38
Investment/cow	664.54	
Debt/cow	13.54	
Asset turnover ratio	0.87	
Return on investment (%)	−11.13	

Adapted from Jones RD: Kansas State University Extension Bulletin MF-2259, April 1997.

A number of management practices associated with increased beef herd profitability in Kansas were identified by Engelken et al (1991) as including use of partial budgeting, fly control, use of growth promotants and creep feeding in calves, precalving parasite control in cows, and improved calf management generally.

Programs that incorporate a number of managerial and veterinary inputs have been shown to increase returns (Anderson et al, 1986; Prince et al, 1987; Deutscher, 1988). The O'Connor system of beef cow management (Anderson et al, 1986), in which a restricted breeding season was combined with prior bull selection, good nutrition management, and early pregnancy testing, was shown to increase weaned calves by 14% and generate an extra $39 per cow. In the Washington program (Prince et al, 1987), which combined cow and heifer measures, increases provided an extra $48 per cow and an estimated 900% return on investment.

Costs of Animal Disease

In this discussion of factors affecting the profitability (and viability) of cow-calf enterprises, it is appropriate to consider the relative cost of disease. Survey data showed that, in selected Colorado beef herds (n = 86), the mean annual cost of disease prevention measures varied from $6.39/cow (Salman et al, 1990) in one survey to $11.24 and

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TABLE 13-9

Sample Cow-Calf Enterprise Production Highlight Summary

REPRODUCTIVE PERFORMANCE MEASURES (%)	
Exposed cows open	5.7
Calving	94.3
Calf death loss	5.7
Calf crop (weaning)	88.7
Female replacement rate	9.4
Calving Distribution (Cumulative)	
First 21 days	20.8
First 42 days	50.9
First 63 days	94.3

PRODUCTION PERFORMANCE MEASURES (LB)	
Steer weaning wt	519.9
Heifer weaning wt	496.2
Avg. weaning wt	507.4
Pounds weaned per exposed female	478.7
Other Information	
Avg. age at weaning (mo)	6.3
Number of exposed females	53.0

Adapted from Jones RD, Simms DD: Kansas State University Extension Bulletin MF-2259, April 1997.

TABLE 13-10

Influence of a 10% Change in Key Factors on Break-Even Price and Return

Factor	Decrease in Break-Even Price ($/cwt)	Increase in Return ($/cow)
Weaned calf crop	9.15	36.87
Weaning weight	7.69	30.75
Calf price	0.00	30.75
Total feed cost	5.83	18.60
Interest cost	1.64	5.25
Cull cow weight	2.08	6.65
Cull cow price	2.08	6.65
Combined	28.47	135.52

From Corah LR: *Practical cow nutrition and economics: bovine bits,* Kansas City, Fall 1995, Kansas State University.

TABLE 13-11

Expected Cumulative Pregnancy and Calving Rates for 100 Cycling, Fertile Females

Expected cumulative pregnancy cycles	Calving rates
1st 21 Days (Cycle 1)	60%
2nd 21 Days (Cycle 2)	84%
3rd 21 Days (Cycle 3)	94%

From Mossman DH, Hanly GJ: *NZ Vet J* 25:96-100, 1977.

$11.29/cow in two others (Salman et al, 1991a,b). This included the cost of vaccines and drugs ($5.11/cow) and the cost of veterinary service ($1.28/cow). In addition, 0.32 hour of labor was spent per cow. Approximately 60% of the total costs of preventive vaccines and drugs was for miscellaneous diseases. The prevention of reproductive diseases accounted for almost the entire cost of preventive veterinary services. Pregnancy examination, brucellosis vaccination of replacement heifers, and breeding soundness examinations were the three procedures that made up the majority of veterinary costs (Salman et al, 1991a,b). The most commonly reported disease entity was diarrhea in calves (25% of all disease cases). The second most commonly reported disease was pneumonia. The total annual cost associated with the occurrence of diseases in beef herds was $20.56 per cow. This included losses from deaths, culled animals, reduced production, veterinary costs for treatment of diseased animals, and miscellaneous expenses. The most expensive disease category on a total cost basis was that in the miscellaneous category, since this covered a large number of cases.

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TABLE 13-12

Cow-Calf Production Costs in Different Geographic Regions of the United States for 1997 to 1998

Region	Northwest	Southwest	Midwest	Southern plains	Southeast
Low-cost producer	$273	$254	$239	$244	$224
High-cost producer	$399	$358	$340	$365	$342

Cattle-Fax Annual Cow-calf Survey Data. Available at http://www.cattle-fax.com (accessed June 19, 2001).

Sudden death–clostridial disease was the next most costly because of the high individual cost. The enteric category was the least expensive, even though it accounted for the second largest number of cases, because the cost per case was low. The cost of veterinary services for treating diseased animals was a relatively small amount of the total cost in each disease category. Veterinary costs were highest for reproductive diseases because of the expense associated with the treatment of dystocia and the treatment of vaginal and uterine prolapses.

Between 1986 and 1988, producers spent an annual average of $2.04 ($0 to $29.88) per cow on veterinary services for the treatment of diseases (Salman et al, 1991a,b). The cost of veterinary services was 5.4% of the total mean cost of disease incidence. Approximately 92% of the mean annual health management costs were associated with pregnancy examination, brucellosis vaccination, breeding soundness examination, pulmonary arterial pressure testing, and campylobacteriosis vaccination. The costs of veterinary services, vaccines, and drugs for treatment and prevention on a per-cow basis also varied greatly among herds. Most of the annual disease costs (over 90%) occurred in other areas, such as vaccine and drug purchases by the producer, as well as costs of labor, losses from lost production, deaths, and transportation.

In 57 California beef cow-calf herds studied in 1988 and 1989, the mean cost associated with episodes of disease was $33.90/cow-year, with $0.78 and $1.37/cow-year spent for veterinary services and drugs, respectively (Hird et al, 1991). For disease prevention, the mean expenditures for veterinary services were $1.67/cow-year, most of which was spent on the prevention of reproductive problems.

In a survey of 60 cow-calf herds in Tennessee in 1987 and 1988, 4% of the total cost of disease was attributable to veterinary services and 2.3% to the purchase of drugs for the treatment of sick animals (New, 1991). The cost of preventive veterinary services accounted for 8.8% of the total cost of all preventive veterinary services. Approximately 68% of the total cost of preventive actions was spent on drugs, with drugs to prevent intestinal and external parasites being the most costly ($5.99 and $1.80/cow-year, respectively). Only 28% of the producers used veterinarians to implement animal health management actions, only 15% used veterinarians to monitor the pregnancy status of cows and heifers, and only 3% used veterinarians as consultants.

Estimates of the financial impact of different veterinary interventions for the United States have been given by Toombs (1996), based on calf prices of 80 cents/lb. At an estimated calf value at weaning of $400, a combination of decreasing calf morbidity (from 50% to 10%) and mortality (from 5% to 1%) led to savings of an estimated $20/cow (or $2000 for a 100-cow herd). A program that increased weaning weights (450 to 500 lb), increased pregnancy rates (90% to 95%), and decreased calf mortality (from 5% to 2%) caused an estimated improved return of approximately $45,000 over 5 years for a 250-head cow herd.

NUTRITIONAL MANAGEMENT OF THE BREEDING HERD

Good nutrition provides the essential basis for optimum productivity in cattle breeding operations. Despite this, nutritional expertise has not been a traditional strength of many food-animal veterinarians.

Throughout the world, beef-breeding operations are generally range or pasture based. These operations are conducted in diverse environments, with great variation in nutritional management. Even within the United States, the area of pasture or rangeland required to maintain a cow-calf unit may vary from 30 acres or more in the southwest to 1 or 2 acres in more intensive regions. In parts of Australia the corresponding area may be measured in square miles. However, in general, the area of land, or amount of pasture, necessary for production is related to local economic realities. This, in turn, is related to levels of managerial and resource inputs that can differ with regions, markets, and enterprise priorities. Notwithstanding such caveats, there are a number of principles of good nutritional management that may be universally applied to cattle breeding operations (Spitzer, 1986). Regardless of region, an important consideration is that of maintaining or improving production while reducing costs. In simple terms, financial return from a beef breeding operation is a function of number of calves, their weaning weight, and price. On the cost side of the ledger is the maintenance cost of the breeding females. This varies considerably, both within and between regions. Market price, in general, is usually unmanageable at the farm level. However, both the number of calves born and their weaning weights are strongly influenced by nutrition. For example, good nutritional management helps to ensure that as many females as possible are cycling at the start of the breeding season. This, in turn, helps to ensure that calves are born early with the result that they are older, and heavier, at weaning than later-born calves, as shown in Fig. 13-2.

In general, nutrition is the most important limiting factor of beef breeding performance. For veterinarians, an understanding of the principles underlying the nutritional management of breeding females is necessary. Effective counseling and troubleshooting does not necessarily require a higher degree in nutrition, although it should include sufficient knowledge and wisdom to know when such expertise is needed. A starting point is to have a working knowledge of the different energy measuring systems (total digestible nutrients [TDN], metabolizable energy [ME], and net energy [NE]) that are commonly used, their applications for different classes of animals, activities and feedstuffs, and to identify one with

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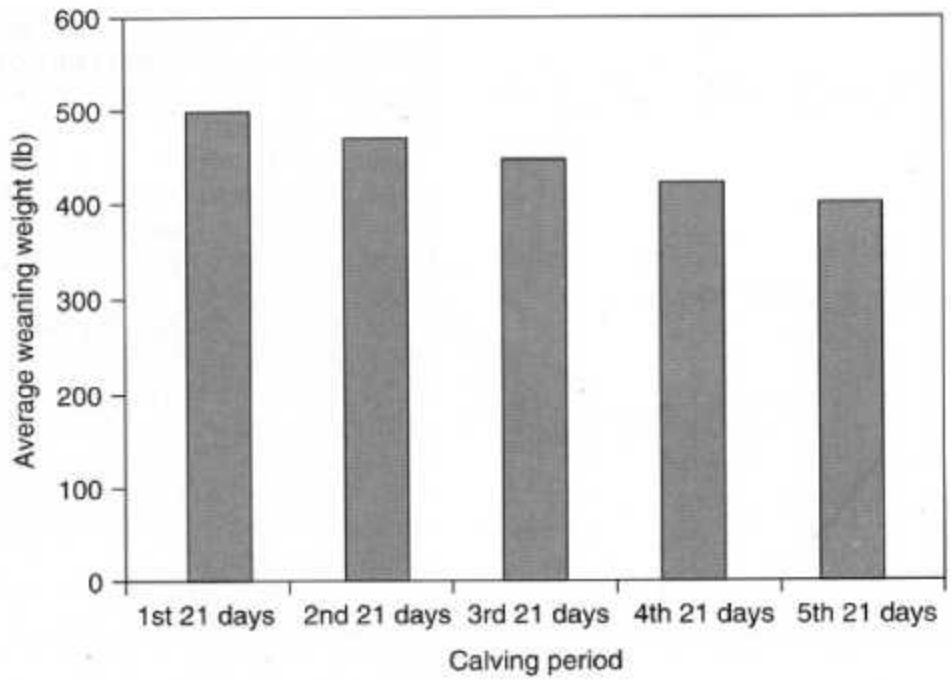

FIG. 13-2 Effect of cow calving time on average weaning weights.

which the veterinarian can work best. The *Nutrient Requirements of Beef Cattle* from the National Research Council (NRC) in the United States is a useful document revised in 2000. This is packaged with a computer program that includes ration formulators as well as a library of feeds and feedstuffs. A number of computer programs are now available for least-cost-ration formulation in beef herds.

A useful concept is animal unit (AU) equivalent values, which allow direct comparison of the resource requirements of different classes of animal. An animal unit is defined as a constant forage demand rate (Kothmann and Hinnant, 1999). An animal unit equivalent (AUE) for any animal type can be obtained by dividing the estimated forage demand of that animal by the selected constant, or benchmark. The number of animals multiplied by their AUEs gives the total number of AUs needed. In turn, stocking rate can be devised by multiplying this total by the number of days grazing a given area, providing animal unit days (AUDs). Table 13-13 lists AUEs for different classes of animals. Here, the benchmark (1.00 AU) is a spring-calving cow (1000 lb) of above-average milking ability with a 3- to 4-month-old calf, grazing adequate quality forage (Table 13-13).

Increasing stocking rate will tend to cause increased gain per unit land area (acre, hectare), but decreased gain per animal. This relationship generally holds true until lack of available forage leads to decreased intake. Optimum stocking rates are attained before this point is reached. Increasing stocking rate beyond this point leads to a decrease in both gains per animal and per land unit area.

Nutrition is a complex topic that includes aspects of forage quality and availability, as well as the contributing roles of water, vitamins, minerals, protein, and energy. Many of these aspects are beyond the scope of this discussion. For more in-depth information, readers can consult the NRC's *Nutrient requirements for beef cattle, update 2000*. A number of computer programs are available to assist with ration formulation. In the present discussion, however, the important contributions of dietary energy to female cyclicity and fertility necessitate that it receive closer scrutiny than other nutritional components. Dietary energy (carbohydrates and fats) may be measured a number of ways including gross energy (GE), digestible energy (DE), ME, NE, and TDN.

GE is the heat of combustion of a feedstuff, expressed as kilocalories per gram (Kcal/gm) or megacalories per kilogram (Mcal/kg). DE is a measure of the amount of energy absorbed by the animal (GE in feed minus GE in feces). ME accounts for extra energy loss, specifically in urine and gases, whereas NE allows an adjustment for the specific dynamic effect of captured energy. TDN has also been used widely to estimate energy content of feeds. TDN is a combination of digestible crude protein (CP) and crude fiber (CF) plus digestible nitrogen free extract (lipids). A rough conversion between systems may be obtained by the following equation:

$$1 \text{ kg TDN} = 4.4 \text{ Mcal DE}$$

TABLE 13-13

Animal Unit Equivalents for Grazing Beef Cattle

Class of cattle	AUE
Cow (1000 lb), with 3-4 mo calf	1.00
Calf, 3-4 mo	0.30
Replacement heifer (24-26 mo)	1.00
Cow (1000 lb), not lactating	0.90
Steer (24 mo)	0.90
Yearling (18-24 mo)	0.80
Yearling (12-17 mo)	0.70
Weaned calf (>12 mo)	0.50
Bull (>24 mo)	1.20
Bull (24-60 mo)	1.50

Cow Nutrition Year

Nutritional requirements vary throughout the "cow year." The most critical periods for reproduction are early postcalving (when maximum lactation is combined with the need for rebreeding) and immediately precalving (when maximum fetal growth occurs along with lactation preparation). Different periods within the "cow year" with varying nutritional requirements have been identified in Table 13-14 (Marston et al, 1998).

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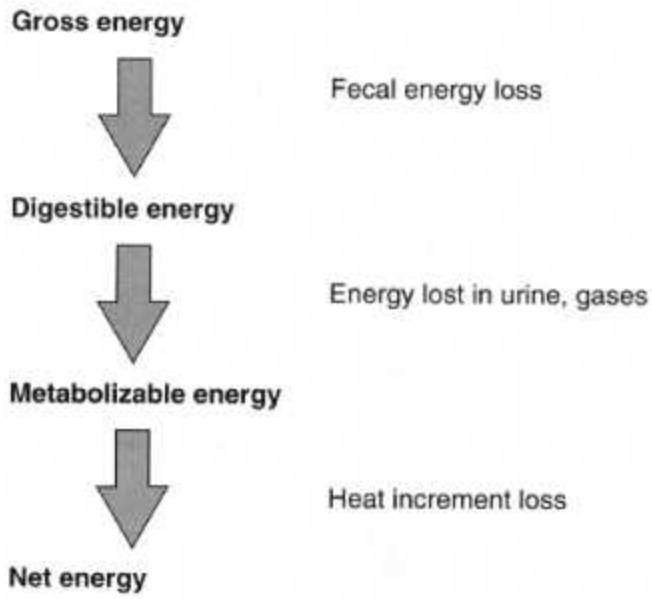

FIG. 13-3 Energy Utilization and Loses.

Environmental conditions can strongly influence the nutritional requirements of cattle, as well as the intake. For example, cold weather increases energy needs whereas hot or inclement weather can reduce foraging opportunity.

When nutrition is limited, the breeding cow meets her needs according to a priority list. First priority goes to maintenance, then growth, followed by milk production, with reproduction last (Marston et al, 1998). Because larger females have greater needs for maintenance, the effect of cow size on fertility should be considered, especially since recent trends have been toward increased growth as well as milk production. Both of these influence nutritional requirements for breeding females, as shown in Fig. 13-4. Here, a 5-lb increase in milk production per cow per day increases the net energy requirements of the cow by 10% and the CP requirements by 13% to 15%. Milk production needs of females are seldom considered by producers (Spitzer, 1986). Cow size also affects nutritional needs, with each 100-lb increase in cow weight changing net energy requirements by 6% to 8%. Thus increases in size and milking ability come with nutritional "costs," which, if not adequately met, will be extracted from the ledger of reproductive efficiency.

The quality and quantity of range forage varies greatly throughout the year and between years, influenced by moisture, plant species, and grazing pressure. Seasonal changes in the nutrient density of rangeland forages are mainly associated with the degree of plant maturity. In general the greatest nutritional value of plants occurs before maturity. Good nutritional management involves matching, as far as possible, the nutrient requirements of cows and nutrient density of the pasture. Some assumptions are necessary, since grazing animals are not fed a ration; they select a diet from the forage available (Kothmann and Hinnant, 1999). Grazing management can influence the quality of this diet. Grazing

TABLE 13-14

*The 365-Day Beef "Cow Year" by Periods**

Duration	Period 1 (Post-calving 80 days)†	Period 2 (Pregnant, lactating, 125 days)‡	Period 3 (Mid-gestation, 110 days)§	Period 4 (Precalving, 50 days)‖
TDN (lb/day)	14.5	11.5	9.5	11.2
Nem (Mcal/day)	14.9	12.2	9.2	10.3
Protein (lb/day)	2.3	1.9	1.4	1.6
Calcium (g/day)	33	27	17	25
Phosphorus (g/day)	25	22	17	20
Vitamin A (IU/day)	39,000	36,000	25,000	27,000

From Marston TT, Blasi DA, Brazle FK, Kuhl GL: *Beef cow nutrition guide*, C-735, 1998, Kansas State University, Agricultural Experiment Station and Cooperative Extension Service.

*For 1100-lb beef cow of average milk production (15 lb/day).

†Period 1 represents the most important period for nutrition in the cow year, in terms of both reproduction and production. As well as nursing a calf (with peak lactation occurring at about 60-80 days postpartum), but she must recycle and rebreed within an 80-85 day window of opportunity to permit a 12-month intercalving interval. Thus nutritional requirements are maximum during this period, with the recommendation that females gain weight between calving and rebreeding. Inadequate nutrition during this period will lead to lower milk production and calf weaning weight as well as reduced rebreeding performance.

‡ During period 2, the cow is lactating although demands should be reducing. The female should also be pregnant, although the demands due to pregnancy should be relatively small. This period often coincides with good forage availability in spring calving programs. Thus period 2 is not usually regarded as a crucial nutritional period for reproduction.

§In Period 3, nursing should be completed while the demands of the developing fetal-placental unit are still relatively low. Thus period 3 is not regarded as a crucial nutritional period for reproduction either.

‖In Period 4, the final 60-90 days of pregnancy represent the second most important nutritional period for beef females. Fetal growth is maximum while fat stores are being augmented in preparation for lactation. Good nutrition at this juncture should aim for females to calve at a body condition score of approximately 5. Inadequate nutrition during this period can cause lighter calves at birth (although dystocia rates are unaffected), lessened calf survival, lower calf growth (because of less milk), and delayed return to estrus.

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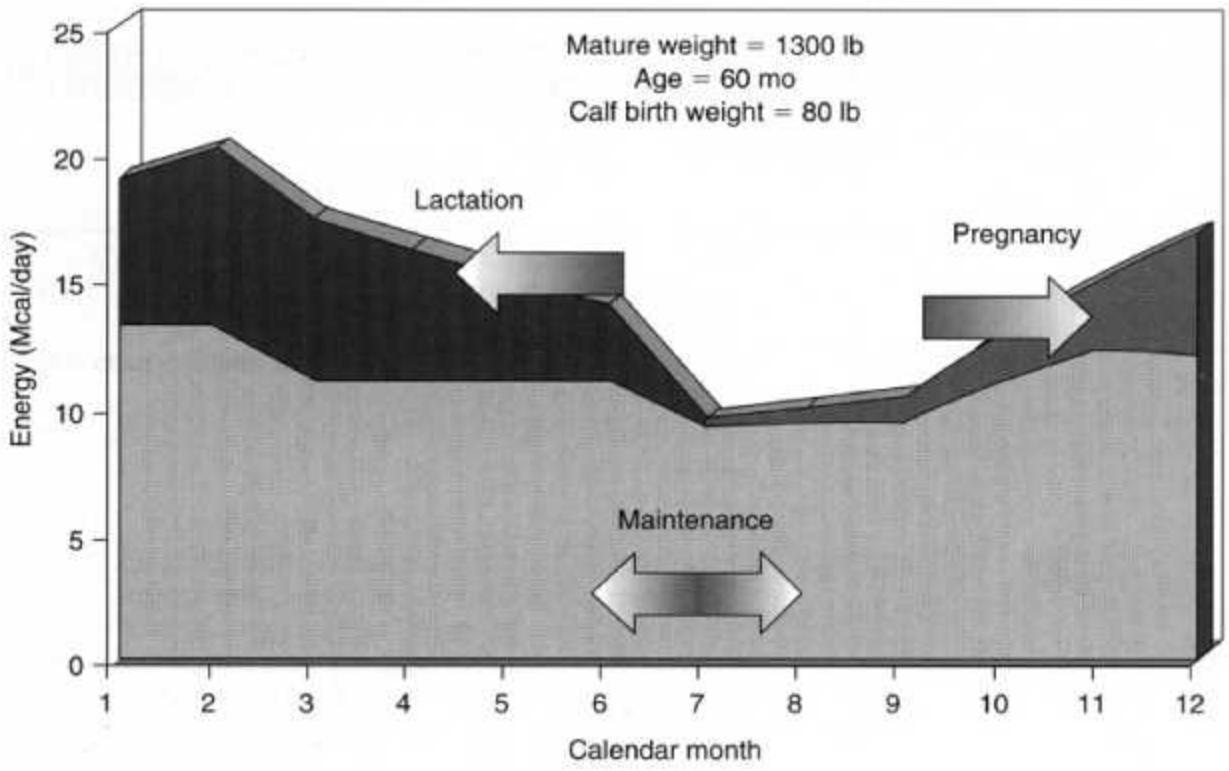

FIG. 13-4 Energy requirements of mature cows.

management includes considerations of factors such as the biological types of animals involved, stocking rates, plant species available, season of grazing, fertilization, and grazing methods used. It should also consider the long-term aspects of the pasture as a renewable resource. A software program—"The Grazing Manager"—assists with this task (Kothmann and Hinnant, 1999).

Body Condition Score

Accurate and timely determination of nutritional status of grazing animals represents a challenge for beef producers, especially because many variables can influence a cow's response to a given level of nutrition (Spitzer, 1986). This is compounded by the fact that relatively few cow-calf operations in the United States appear to use weigh scales (NAHMS/CHAPA, 1993). Fortunately, a large body of evidence exists to support the use of BCS as an effective indirect method for determining nutritional status in breeding females. This is reinforced by observations that BCS, and changes in BCS, are more reliable indicators of nutritional status than is body weight, or changes in body weight, which can vary with gut fill and pregnancy status (Kunkle et al, 1994). In addition, the assessment of BCS can often be made more conveniently than can the measurement of body weight.

BCSs represent a subjective assessment of body fat (or energy reserves), which is strongly related to female reproductive performance (Kunkle et al, 1994). Several systems exist, with a 1-9 system (Richards et al, 1986) most widely used within North America (Table 13-15). Another system in use is the ESCA 1-4 system, whereas a 1-9 system has been described for use with *Bos indicus* cattle (Nicholson and Butterworth, 1986).

BCS is not difficult to obtain, and it is both repeatable and accurate in experienced hands. It is best done through visual appraisal, reinforced by palpation of those body regions most likely to demonstrate fat deposits. For beginners, it is advisable to practice by comparing assessments with someone who is more experienced.

Use of Body Condition Scoring

BCSs generally vary throughout the year, and they should be monitored regularly. The "benchmark" for beef females is a BCS of 5, which represents an average, moderately fleshed cow that is neither fat nor thin. However, the BCS for optimum female efficiency varies with breed and operation and may be higher or lower under different conditions (Corah, 1989). In general, females should calve between condition scores 4 to 6 and then gain slightly to breeding. In this range of scores, a 1000-lb female gains or loses approximately 70 lb/condition score. It generally takes about 2 months to gain 1 score under pasture conditions. Care should be taken with overreliance on "averages," since these can mask variations that might adversely affect herd fertility levels. Care should also be taken with group observations of BCS made from a distance when animals are in the pasture or paddock. In general, such observations are less accurate than those made when animals are proximate in the pen or chute. Proximate assessment is often dependent on opportunity, as when animals are gathered for other managerial reasons such as prebreeding, pregnancy testing, or calving. Whereas each of these occasions presents particular advantages and disadvantages, the BCS-pregnancy relationships of each occasion appear to be similar (Fig. 13-5).

Despite similar relationships between BCS assessments at different periods in the cow-calf cycle and subsequent breeding success, managerial and logistic differences do occur with assessments at these different junctures, as explained in the following sections.

Body Condition Scoring at Calving

The body condition score of females at calving can tell much about their rebreeding prospects (Spitzer, 1986). However, assessment of BCS at this time provides a relatively small window of time in which to meet targets. Thus 1000-lb cows calving at BCS 4 might have, for example, 60 days before they reasonably might be expected to be bred at

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TABLE 13-15

System of Body Condition Scoring for Beef Cattle

Group	Score	Description
Thin	1	*Emaciated:* Extreme emaciation, no detectable fat over bony protuberances. Tailhead and ribs are prominent. Animal often weak.
	2	*Poor:* Cow somewhat emaciated, less prominent bony protuberances, some tissue cover along spine.
	3	*Thin:* Ribs individually identifiable, but less sharp. Some fat along spine and over tailhead, some tissue cover over the dorsal aspect of the ribs.
Borderline	4	*Borderline:* Individual ribs no longer visually obvious. Spinous processes individually palpable, although rounded. Some fat cover over ribs, transverse processes and around tailhead.
Moderate (optimum)	5	*Moderate:* Generally "good" appearance; fat over ribs is spongy and areas lateral to tailhead have fat cover.
	6	*High moderate:* Firm pressure necessary to feel spinous processes; fat is observable and palpable over ribs and around tailhead.
	7	*Good:* Cow appears "fleshy" and obviously carries considerable fat. Very spongy fat cover over ribs and around tailhead with "rounds" or "pones" beginning to become obvious. Some fat around vulva and in crotch.
Fat	8	*Fat:* Cow is very fleshy and "overconditioned." Spinous processes almost impossible to palpate. Large fat deposits over ribs, around tailhead, and below vulva. "Rounds" or "pones" are obvious.
	9	*Extremely fat:* Cow obviously extremely "waisty" and patchy and has block-like appearance. Tailheads and hips are buried in fatty tissue, and "rounds" or "pones" of fat are protruding. Bone structures not visible and barely palpable. Mobility may be impaired.

Adapted from Richards MW, Spitzer JC, Warner MB: *J Anim Sci* 62:300-306, 1986.

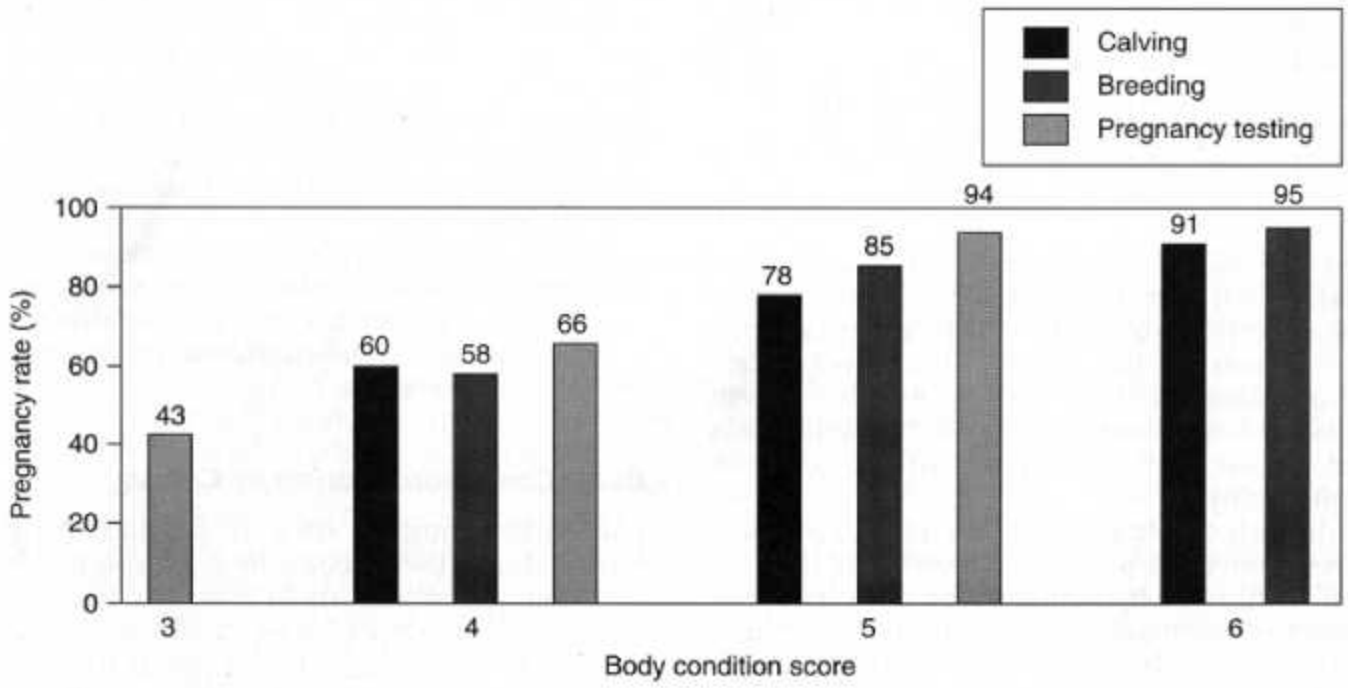

FIG. 13-5 Relationship between body condition score at different events and pregnancy rates.

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a BCS of 5. Assuming that this change in 1 BCS score represents an increased body weight (BWT) of approximately 70 lb, then these females will need to gain slightly more than 1 lb/day (0.45 kg/day) in the interim—a gain that must coincide with the period of maximum milk production. A disadvantage of conducting BCS at calving is that it necessitates either gathering cows with very young calves, which is often inadvisable, or using visual assessment from a distance in the pasture or paddock, which tends to cause errors.

Body Condition Scoring at Breeding

Assessment of body condition in females at breeding should provide the most accurate prediction of herd fertility, since it occurs just before the predictive event. The disadvantage is that there is little opportunity to correct significant shortfalls in time to affect the current breeding season, unless this is prolonged.

Body Condition Scoring at Pregnancy Checking

Assessment of body condition at the time of pregnancy checking has the advantage in that it can be done in concert with a routine, managerial procedure, thus not requiring a separate animal handling. It also allows considerable time to remedy obvious deficiencies before calving and then subsequent rebreeding. The disadvantage is that, although it can provide clues to explain current pregnancy patterns, it is too late to remedy them.

Mineral Supplementation

Mineral requirements are generally placed into two groups: major minerals (calcium, phosphorous, and salt) and trace minerals (or microminerals), which usually have much lower requirements. Table 13-16 shows minerals for which nutrient allowances for beef cattle have been established (calcium and phosphorus levels are shown in Table 13-14).

Several microminerals have been identified that can affect different reproductive functions in cattle, including cyclicity, fertility, and survival of early pregnancies. Both low copper and magnesium have been associated with increased services per conception as well as increased early embryonic death (EED) lactating dairy cows (Ingraham et al, 1987), whereas low copper and zinc levels have been associated with suppressed estrus expression (McDowell, 1992; Herd, 1994). Copper, zinc, manganese, and cobalt have all been associated with decreased postpartum cyclic activity (Doyle et al, 1999), whereas manganese deficiency in older females has also been associated with depressed conception rates, abortion, stillbirths, and low calf birth weights (NRC, 1996). In turn, elevated levels of manganese significantly reduced days to conception (Doyle et al, 1999), whereas application of phosphorus, copper, manganese, and zinc on native pasture improved reproductive performance in lactating beef cows, without evident change in body condition (Doyle et al, 1988). Iodine deficiency may have delayed effects such as irregular cyclicity, low conception rate, and retained placenta in females, as well as depressed libido and semen quality in bulls (NRC, 1996).

Male Nutrition

As with females, postweaning rate of gain influences both weight and age of puberty in bulls, with puberty often defined as the age at which the first ejaculate containing 50×10^6 sperm with a minimum of 10% motility (Wolf et al, 1965) is obtained. In general, low nutrition during this period will delay puberty in association with delayed testicular growth and sperm production (Bellows and Short, 1994; Swecker, 1997) although genotype-environment interactions occur with such relationships, particularly with *Bos indicus* genotypes in subtropical or tropical environments (Perry et al, 1991; Chase et al, 1997). Diets adequate in protein, vitamins, minerals, and energy appear to hasten the onset of puberty in beef bulls (Coulter and Kastelic, 1999), although high-energy diets for postpuberal bulls do not appear to be beneficial to some reproductive traits and may actually be harmful (Coulter and Kastelic, 1999). A multisire natural breeding study, in which calf crop was established by

TABLE 13-16

Mineral Requirements and Tolerance Levels for Beef Cattle

Mineral	Unit of Measure	Gestation	Early Lactation	Maximum Tolerance
Cobalt	ppm	0.1	0.1	10
Copper	ppm	10	10	100
Iodine	ppm	0.5	0.5	50
Iron	ppm	50	50	1000
Magnesium	%	0.1	0.2	0.4
Manganese	ppm	20	40	1000
Molybdenum	ppm	—	—	5
Potassium	%	0.6	0.7	3
Selenium	ppm	0.1	0.1	2
Sodium	%	0.06-0.08	0.1	—
Sulfur	%	0.15	0.15	0.4
Zinc	ppm	30	30	500

Taken from an adaptation of material from NRC: *Nutrient requirements of beef cattle*, ed 7, 1996, by Marston TT, Blasi DA, Brazle FK, Kuhl GL: *Beef cow nutrition guide*, C-735, 1998, Kansas State University Agricultural Experiment Station and Cooperative Extension Service.

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parentage, showed that increasing backfat thickness was associated with reduced fertility (Coulter and Kozub, 1989). The harmful effects of high-energy diets during the peripuberal and postpuberal periods may be long lasting and may affect sperm production, semen quality, and sex drive. The exact mechanisms for the deleterious effects of high-energy levels on sperm parameters is unknown, although adverse effects on testicular thermoregulation as well as stress-induced hormonal imbalances have been mooted (Coulter and Kastelic, 1999). In general, bulls should be in good, athletic condition at the start of the breeding season, with the expectation that an active, mature bull may lose 1 to 200 lb in body weight over the course of an intensive breeding season. Such loss of weight in mature bulls has not been shown to adversely affect sperm production, unless specific dietary deficiencies occur.

Specific dietary deficiencies that have been associated with bull infertility include zinc and selenium (Swecker, 1997). Gossypol, a component of cottonseed, can adversely affect both spermatogenesis and sperm morphology in bulls (Chenoweth et al, 1994), although the spermatoxic effects of gossypol may be countered with dietary vitamin E (Velasquez-Pereira et al, 1998).

Nutritional Effects on Immunocompetence

A general association between nutrition and health has been recognized for many years. For example, general malnutrition can cause reduced disease resistance by altering immune responses (Franco, 1998). A depressed immune system, in turn, causes increased susceptibility to disease, reduced immunological response to vaccines, and nonresponsive medical therapy (e.g., with antibiotics or anthelmintics). A functional immune system requires adequate energy, protein (or amino acids), minerals (calcium, phosphorus, iron, zinc, copper, cobalt, and selenium), and vitamins A and D (Doyle et al, 1999) to sustain its different mechanisms. The interaction between nutrition and immunity is complex and is complicated by a wide variety of both disease threats and disease types of immune response that may be evoked. This topic is covered in detail by Doyle et al (1999).

HEALTH AND PRODUCTION MANAGEMENT PROGRAM

A cost-effective and efficacious herd health and production management program is essential for the economic viability of most cow-calf operations. What such a program entails, however, varies with region, relative economics, perceptions, and opportunity. A good herd health program manages risk of disease and lowered productivity at a number of levels and reflects the complexity of maintaining immunocompetence in both individuals and groups. These levels include considerations of biosecurity, nutrition (both macro and micro), and the judicious use of biologicals such as vaccines. The term *immune system management* is used to describe this holistic view of herd health (Stokka and Faulkner, 1998). Here, both reproductive, nutritional, and health management overlap. For example, the adoption of a restricted breeding season (e.g., 40 to 65 days for cows and 30 to 45 days for heifers) is advantageous to herd health since it allows groups of animals to be managed and treated similarly.

The role of the herd health provider in developing herd health programs has a large educational component (Spire, 1988). Producers in the United States rely heavily on veterinarians for relevant information on herd health (NAHMS, 1994a). However, despite the privileged position of veterinarians as advisors on herd health, a considerable number of producers do not appear to have health programs that supply even minimum protection against common pathogens. For example, in a survey of 169 producers in northwest Kansas, Spire (1988) reported that the following vaccines were used in cows and heifers respectively: none (31.3%, 28.4%), *Campylobacter* (55.6%, 44.4%), *Leptospirosis* (62.1%, 53.2%), *Clostridia* (5.3%, 23.6%), IBR (11.2%, 19.3%), bovine viral diarrhea (BVD) (11.2%, 13.6%), and *Rotavirus-Coronavirus* (10.6%, 5.9%).

A more recent survey from a wider geographical sampling of cattle breeding operations in the United States (NAHMS, 1998a) indicated even less vaccination activity overall. The most common vaccination was calves for *Clostridial* diseases between 3 weeks of age and weaning (approximately 62% of operations), and this group also received most vaccinations against IBR, BVD, PI3, and BRSV. For cows, most vaccinations were against reproductive disease, such as *Leptospirosis* 28.5% of operation and *Campylobacter* 20.1%. Other vaccinations included bovine respiratory disease (BRD) and clostridia, both approximately 14%; *Escherichia coli*, 4.7%; *Rotavirus* and *Coronavirus*, 4%; and *Trichomonas foetus*, 1.1%. Bred heifers were generally not subject to as much vaccination as cows or heifers before breeding. For the latter group, vaccinations included leptospirosis, 18.0% and IBR and BVD, approximately 17%. Only 11% of heifers were vaccinated against *Campylobacter* before breeding, and 0.2% against *Trichomonas foetus*. A somewhat brighter picture emerged from a survey of 53 beef cow calf producers in the Rocky Mountain West (Sanderson and Gay, 1996), where considerably higher utilization rates were reported. Here, over 60% of producers vaccinated cows for *Clostridia*, 87% for *Leptospirosis* and 85% for *Campylobacter fetus* (79% heifers). However, even though this survey was conducted with progressive ranchers, it suggested that management practices were not adjusted for relative risk, especially when purchasing cattle of unknown origin. This was confirmed in survey data that showed that only a third of operations quarantined new additions to the herd (NAHMS, 1997b).

Although apparent opportunity exists for many producers to improve their levels of herd protection and biosecurity, producers themselves have nominated the following as serious disease concerns (NAHMS, 1994b): external parasites (67%), internal parasites (61%), females not breeding or breeding late (e.g., reproduction) (50%), pinkeye (41%), calf scours (31%), footrot (26%), abortion (14%), weak calves (22%), and calf pneumonia—shipping fever (23%).

MARKETING OF HERD HEALTH CONCEPTS

For many producers, the sheer number of potential disease threats, and the biological and therapeutic products available for their prevention or treatment on the market, is bewildering. Here, veterinarians can play a valuable role in simplifying and translating this information into effective, practical, cost-effective herd health programs. In the past such advice has been given freely, and veterinarians have relied on associated services and product sales as major income generators. This is changing as producers perform more and more services previously regarded as solely within the veterinary domain, and, at the same time, veterinarians are finding it increasingly difficult to compete with other sources for product sales. Over 15 years ago, U.S. veterinarians identified the growth of herd health management services as the area with greatest potential for revenue growth (Wise, 1987). Today this is still an area of largely untapped potential.

The problem is to identify ways for veterinarians to better market their health knowledge for cow-calf producers. Estimates of the value of herd health programs to producers are difficult to generate, although Toombs (1996) has estimated

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TABLE 13-17

Benchmarks for Cow-Calf Operations

Trait	Goal	Monitor	Action
REPRODUCTION			
Calf crop (%)	>90	85-90	<85
60-Day pregnancy rate (%)	>95	90-95	<90
1st 20-Day pregnancy rate (%)	>65	55-60	<50
HERD			
Average cow age (yr)	5-6	4-5, 6-7	<4, >7
Body condition score			
Mid-gestation	4.5-6.0	4.0-4.5	<4
Calving	5-6	4.5-5.0	<4.5
Adult dystocia (%)	<5	6-7	>8
Heifer dystocia (%)	<15	20-25	>25
Losses during pregnancy (%)	<2	2-3	>3
Perinatal losses (%)	<5	5-9	>10
Annual cow loss (%)	<2	3-4	>5
Culling rate (%)	15-20	10-14, 20-25	<10, >25

From Spire MF: Proceedings of the American Association of Bovine Practitioners Annual Convention, West Lafayette, Ind, 1990.

higher returns of $5 to $20/cow when an effective vaccination program is used. Generic programs for all producers are of limited value. Each operation is a unique entity, with its own risk factors, economics, and priorities—factors that should be reflected in an individually tailored, documented, herd health program. Not only should each operation have a tailor-made herd health program, but it should be reexamined regularly (Gay, 1999).

Access to herds and the development of mutual confidence may be achieved by applying "marketable skills"; veterinary procedures or techniques that are of proven economic benefit (Chenoweth, 1989). A number of these exist, ranging from individual animal diagnosis and treatment to palpation skills, bull evaluation, financial management, and risk assessment. In the herd health context, appropriate marketable skills would include diagnostic and economic analyses, nutrition counseling, and data handling, including epidemiology.

For a particular herd, a starting point is to identify current production losses by comparing the performance of the herd with relevant benchmarks. These may be established for a given region, or from national surveys such as those obtained through SPA, which can also provide an economic estimate of losses. Table 13-17 gives an example of such benchmarks for the U.S. Midwest.

The next step is to conduct cost-benefit projections of different herd-health options. Final decisions depend on a number of factors, which may not all make perfect economic sense. However, decision making may benefit from use of "what-if" computer simulation software, such as DECI (Decision Evaluator for the Cattle Industry) developed by the USDA in conjunction with the National Cattlemen's Beef Association (NCBA) (Roybal, 1999), which can provide long-term estimates of the production and financial consequences of different managerial decisions.

Concurrently, veterinarians should work with clients to establish a list of disease threats to the herd and then rank them according to their potential to cause disaster. Richey (1991) described the process as follows:

1. Recognizing the disease challenge (diagnosis and surveillance)
2. Knowing when and why a particular challenge will occur (pathogenesis)
3. Lowering (or eradicating) the challenge (management)
4. Raising resistance both to the specific disease and in general (immune system management)

Identification of potential disease challenges for a beef herd in any region can be a challenge. As a starting point for North America, a list may be compiled as shown in Box 13-9.

Local knowledge and advice from producers, extension personnel, and diagnostic laboratories will help to narrow this list down to those most prevalent for each region. Once a list of potential pathogens is established for a region, the next step is to assign relative risk for each class of cattle most likely to be affected and when they are most at risk. For example, a list of the major pathogens associated with reproductive wastage in beef cows in North America, with relative risk for each gestational period, may be tabulated (Table 13-18). Such a list of infectious disease entities and their relative risk can be used to determine the cost-benefits of different approaches to herd protection, or, at least, risk reduction. Here, it is useful to consider the different components of herd health (after Richey, 1991).

A herd is "healthy" when its collective resistance is greater than the disease challenge. Effective herd health programs act to raise resistance, reduce the risk of disease challenge, or both. A challenge may occur when a pathogen is introduced to a susceptible population (or animal), or when an overwhelming infection occurs in a normally resistant population (or animal). Factors associated with changes in resistance and challenge levels can include those shown in Box 13-10.

Box 13-10 shows that a number of options exist to keep a herd "healthy" and disease free. To devise the "best" option for each situation requires the veterinarian to have a good understanding of the animal populations involved and their environment, plus management priorities and constraints.

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BOX 13-9

Disease Challenges To North American Beef Herds

Infectious bovine rhinotracheitis
Haemophilus somnus
Leptospirosis
Brucellosis
Helminths
Buffalo fly
Bovine viral diarrhea
Mannheimia (Pasteurella) Haemolytica
Anaplasmosis
Escherichia coli
Lung worm
Ticks
Parainfluenza-3
Clostridia spp.
Campylobacteriosis
Rotavirus
Lice
Bovine respiratory syncytial virus
Redwater
Trichomonosis
Coronavirus
Flukes

From Richey EJ: *Large Anim Vet* 46(3):8-16, 1991.

BOX 13-10

Factors that Raise and Lower Herd Susceptibility to Disease

INCREASING SUSCEPTIBILITY
Increasing population density
Contamination
Commingling
Poor nutrition
Stress
Genetics
Failure of passive transfer

DECREASING SUSCEPTIBILITY
Biologicals
Exposure
Nutrition
Genetics
Quarantine/closed herd
Remove/isolate infected animals
Hygiene/sterilization
Parasite control
Antibiotics

TABLE 13-18

Beef Cow Reproductive Pathogens and Relative Risk by Gestational Period

Pathogen	Gestational Period			
	Early	Mid	Late	Periparturient
Aspergillus fumigatus		L		
Bluetongue virus	L		M	L
Bovine viral diarrhea virus	V	H	L	L
Brucella abortus	L		H	L
Campylobacter fetus ssp. *venerealis*	H	M		
Chlamydia psittaci			L	
Haemophilus somnus	L		H	M
Infectious bovine rhinotracheitis virus	L	M	H	L
Leptospirae	L		H	L
Listeria monocytogenes			L	
Mixed bacterial			L	L
Parainfluenza 3 virus				L
Ureaplasma diversum	V	V	V	

From Spire MF: *Compend Contin Educ Vet Pract* 10:1111-1118, 1988.
H, High; *L*, low; *M*, moderate; *V*, variable/not fully understood.

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The risk level of the herd varies according to its potential to be exposed to particular pathogens, with the terms "open," "closed," and "modified open" being used to describe degree of risk (see below).

Herd Health Calendar

The major disease risks for a given herd, and appropriate preventive measures, should be established in consultation with herd owners. For a given disease, the options may include the following: (1) ignore, (2) minimize risk managerially, or (3) use biologicals. If biologicals are being considered, veterinary advice should include the relative efficacy of different products, their formulation and duration of effect, handling and storage information, contraindications and cost effectiveness. A "good" vaccine should decrease the number of susceptible animals, increase the level of collective herd immunity, and have a minimum of deleterious effects (Spire, 1988).

The best times for herd intervention must be established. These will often coincide with other major managerial tasks, or events, for the cow-calf operation. One approach is to devise a herd-health "calendar" in which the health events are coordinated with major operational events. An example of such a calendar for a spring calving herd is given in Table 13-19.

The normal activities that occur during the course of 12 months in a beef breeding herd can be grasped easily if illustrated diagrammatically through a system of circles and windows (Richey, 1992). Such diagrams are also helpful with client communication. In Fig. 13-6, the cow year for a generic herd is shown as the major circle, with a smaller circle representing the breeding season (in this case, 90 days). Veterinarians should work closely with producers to develop such plans, since each operation is different. The health program should be designed to "fit the management" (Richey, 1992). In order to construct such a herd health program for a client, several key dates need to be obtained and inserted, as shown in Table 13-20, with the given dates used as examples only. Relevant information that may affect many of these considerations include breed types, normal herd working dates (cow and calf), calf weaning date, calf management (e.g., creep feeding), age of breeding of replacement heifers, source of bulls, and previous disease problems.

Inclusion of the above dates for the "Wildcat Ranch" would cause a cow-calf annual cycle as shown in Fig. 13-7.

Herd health procedures should be synchronized with major routine managerial events as much as possible to minimize herd disruption and labor costs. With the "Wildcat Ranch," coordination of health and managerial events may be achieved as shown in Fig. 13-8. Here, major herd health intervention opportunities are synchronized with managerial "events" as much as is feasible. Possible intervention opportunities are represented by numbers and small, dark circles and are discussed below.

Intervention windows of opportunity vary with different enterprises, and some may be combined (e.g., precalving and prebreeding). Similar "cycles," with inclusion of their own specific health intervention "windows," may be constructed for each class of cattle, such as heifers, bulls, and calves.

Notes to Accompany Cow-Calf Health Programs

Breeding Considerations

A restricted breeding season is advantageous to an effective preventive herd health program (PHHP) (Stokka and Faulkner, 1998). Here, as a general principle, heifers should be bred before the main cow herd and for a shorter period. This allows selection pressure to be exerted for fertility and allows particular attention to this group at calving time. This may, however, not be a practical option in a number of herds, particularly where genotypes or environments present difficulties in achieving target weights on schedule. Prescreening of bulls and use of good bull management principles optimize calf crops with use of fewer bulls. For AI programs, facilities and procedures should be established before the program begins, especially if estrus synchronization is planned.

Prebreeding vaccinations should be completed within 2 to 4 weeks of the start of breeding. The major diseases to consider here are campylobacteriosis, trichomoniasis, leptospirosis (five strains), IBR, and BVD.

Preweaning

Preweaning is an important intervention because it can help prepare calves for the stress of weaning and reduce the possibility that such stress will compromise the efficacy of biologicals. Common vaccinations here include the clostridials, BRD (IBR, BVD, PI3, BRSV plus *Haemophilus somnus* and *Pasteurella* spp.), and leptospirosis. For BRD vaccinations, only products licensed for suckling calves should be given. A broad-spectrum anthelmintic may also be given at this time to ensure that calves cause minimal pasture infestation.

Weaning

Good weaning management includes preparing calves by allowing them prior access to the weaning facility, feed, and water. It also entails weaning into a clean area, with fresh feed and water. At weaning, a second vaccination should be given for those products recommending two injections. Modified live viral products can be given at this stage. Another clostridial vaccination is not indicated if calves were previously vaccinated at working and preweaning. Implanting may be done here on animals not intended for reproduction. Parasite and grub control may be done here also, although timing should coincide with calendar recommendations for the latter. For areas where brucellosis is under regulatory control, heifer vaccination with either St19 or RB51 should be given within the age "window" stipulated.

Pregnancy Examination

Pregnancy examination should be conducted ideally as soon as possible after breeding, allowing for detection of those animals that got pregnant last. For practical purposes, this is probably 45 days or more after the end of breeding. For other operations, it may be more convenient to schedule the pregnancy examination to coincide with weaning.

This is an important intervention time. Here, cull females are identified. These include some or all animals that are classified as nonpregnant and those that qualify on the grounds of age, soundness, or disease. Veterinary procedures such as removal of squamous cell carcinoma of the eye (cancer eye) may be done, or scheduled, at this stage.

For pregnant animals, important information should be recorded on stage of pregnancy, age, parity, body condition, and lactation status ("wet" or "dry"). Other relevant information, and its analysis, is discussed earlier in this chapter.

Precalving

A precalving intervention may coincide with pregnancy testing, although the ideal time is about 1 month before calving. The vaccinations here are intended to protect the newborn calf through colostral transfer. Thus important antigens include those of the major clostridial diseases (particularly *Clostridium perfringens*), leptospirosis (5-way) as well as those for calf scour pathogens (*E. coli, Rotavirus, and Coronavirus*),

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TABLE 13-19

Herd Health Calendar for a Spring Calving Herd

Season/Group	Cow	Heifer	Calf	Bull
Late winter–early spring	**Calving** Dystocia check **Prebreeding*** Check BCS, udder, teeth. Vax: vibrio, trichomonosis. Rising nutrition. Deworm, defluke external parasites. Cull problem animals.	**Prebreeding** Check target wt, BCS, RTS, pelvic measure. Vax: vib, trich, Lepto (5), *Clostridia*, BRD. Deworm, defluke external parasites. Breed early. **1st Calving** Separate and monitor.	**At birth** Dystocia check Check newborn: birth wt, navel, colostrum, ID. Brand, castrate, dehorn, implant. Vax (calves should be at least 8 wk old): *Clostridia*, BRD, pinkeye.	**Prebreeding** BSE. Libido/serving capacity test. Vax: Lepto (5), vibrio, *Clostridia*, BRD. Deworm, defluke external parasites. Bull selection or purchase: check EPDs, do BSE, check vib/trich.
Late spring–early summer	**Breeding** Control external parasites.	**Breeding** Control external parasites.	**Working** Brand, castrate, dehorn, implant. Vax (calves should be at least 8 wk old): *Clostridia*, BRD, pinkeye. Deworm.	**Breeding** Monitor. Control external parasites.
Late summer–early fall (autumn)	**Gestation** Pregnancy test. Parasite control. Cull open/problem cows. Supplementation.	**Gestation** As for cows.	**Pre-weaning** Calf boosters–Vax: *Clostridia*, BRD. Implant, parasite control	**Postbreeding** Check soundness, nutrition, parasite control.
Late fall–early winter	**Precalving** Vax: Lepto (5), BRD, *Clostridia*, calf diarrhea, vitamins A and D. Lice control. Check BCS, supplementation. Check calving details.	**Pre-calving** As for cows.	**Weaning** 2nd Vax.	Monitor herd bulls.

BCS, Body condition score; *BRD*, bovine respiratory disease; *BSE*, breeding soundness evaluation; *EPD*, expected progeny differences; *lepto*, leptospirosis; *RTS*, reproductive tract score; *trich*, trichomonosis; *Vax*, vaccination; *vib*, vibriosis (campylobacteriosis).

*Pre-breeding working opportunity may not be available, depending on breeding season length. Appropriate herd health procedures (particularly vaccinations) then should be given in the latter part of gestation. If so, avoid replicating virus vaccines, particularly infectious bovine rhinotracheitis and bovine viral diarrhea.

respiratory disease (IBR, BVD, PI3, BRSV plus *H. somnus* and *Pasteurella*) and redwater where these represent significant problems.

Replacement Females

Replacement females should be subjected to the same vaccinations as those given to females before breeding.

Bulls

In general, the bulls should be subjected to the same vaccinations as the cow herd, with several major exceptions. First, bulls should not be vaccinated for brucellosis. Second, the trichomonosis vaccine currently approved for use in the United States is not approved for bull use. Caution is advised with modified live virus (MLV) IBR vaccines, since bulls may recrudesce this virus and shed it in semen. Also,

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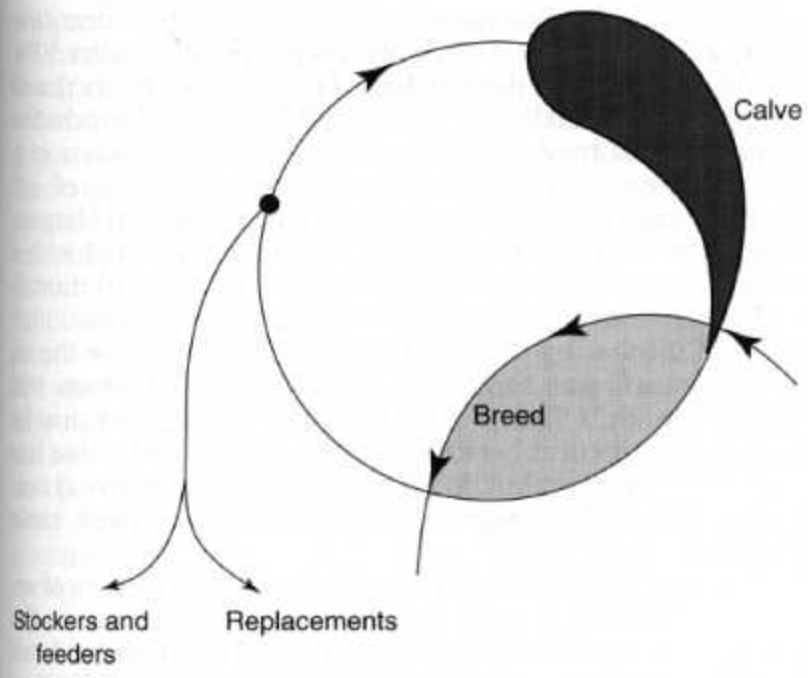

FIG. 13-6 Cow-calf annual cycle. (Adapted from Richey EJ: *Constructing diagrams to represent the management system of a beef herd,* University of Florida IFAS/Cooperative Extension Service Bulletin no. 278, 1992.)

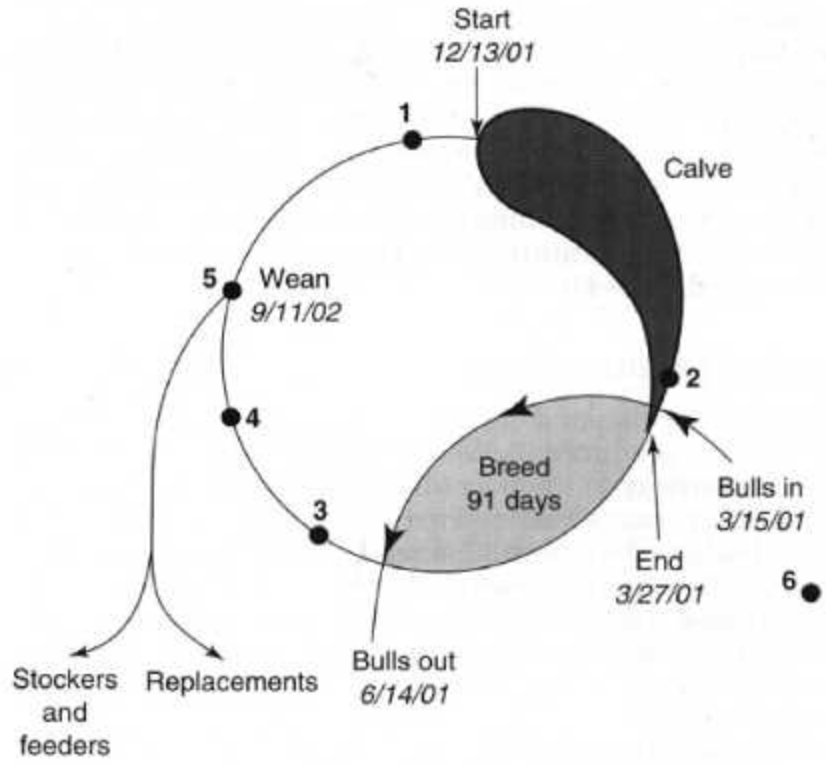

FIG. 13-8 "Wildcat Ranch" cow herd-health management plan. (Adapted from Richey EJ: *Constructing diagrams to represent the management system of a beef herd,* University of Florida IFAS/Cooperative Extension Service Bulletin no. 278, 1992.)

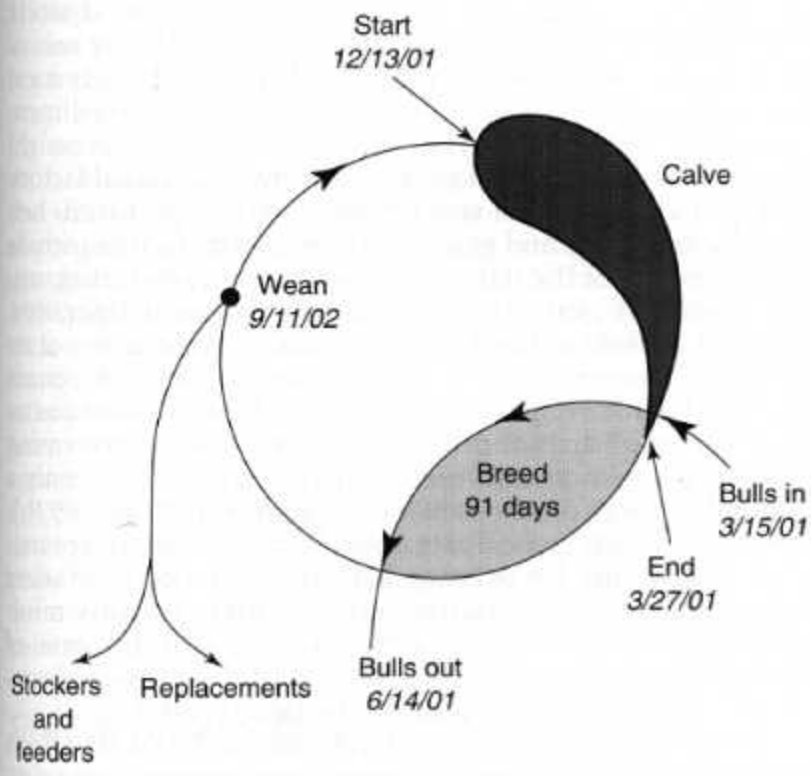

FIG. 13-7 "Wildcat Ranch" annual cow-calf cycle with major event dates. (Adapted from Richey EJ: *Constructing diagrams to represent the management system of a beef herd,* University of Florida IFAS/Cooperative Extension Service Bulletin no. 278, 1992.)

TABLE 13-20

Dates for Major Cow Calf "Events" on the "Wildcat Ranch"

Event	Adult Cow Herd	Replacement Heifers
Start of breeding season	3/15/01	2/15/01
End of breeding season	6/14/01	5/17/01
Length of breeding season	91 days	91 days
Length of gestation (HxA)	283 days	283 days
Start of calving	12/13/01	11/15/01
End of calving	3/27/02	2/28/02

semen shipment to other countries may be jeopardized. Otherwise, recommended bull vaccinations include leptospirosis (5-way) and campylobacteriosis, in accord with recommendations for the cow herd.

CALVING MANAGEMENT

The endpoint of a cow-calf enterprise is the profitable production of calves. The goal is to obtain and maintain a live calf to weaning. Management of the calving season is critical to optimizing the weaned calf crop. According to the NAHMS *Beef '97* survey, 58% of calf mortality from birth to weaning occurred within 24 hours of birth, and 78% of calf mortality occurred within the first 3 weeks after birth. Total mortality from birth to 3 weeks of age was 3.3% and from birth to weaning was 5.5% (NAHMS, 1997b). These survey results are consistent with other research indicating 57% of mortality occurred in the first 24 hours and 75% within 7 days of birth (Patterson et al, 1987). Significant risk factors for increased calf morbidity are also active at the time of calving and can lead to increased death loss and decreased calf performance. Wittum et al (1994b) found a 16-kg reduction in weaning weight in calves that experienced a morbidity incident from birth to 45 days of age. These results highlight the importance of proper calving season management practices for optimum production. Current calving management performance and practices of U.S. cow calf herds as reported in the NAHMS *Beef '97* survey are summarized in Table 13-21.

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Target goals for calving management as reported in the literature are arbitrarily based on levels achieved by "good" producers (Spire, 1991). These serve as a good starting point for assessment of productivity but may not be the optimum level of production for the individual herd. Optimum production must be based on financial and economic inputs and returns for the individual herd. SPA has proved useful for identifying the optimum level of production (Hamilton, 1995). The key factors to control in calving management are shown in Box 13-11.

Dystocia Management

Calving difficulty, or dystocia, is the major cause of calf loss for cow-calf producers. Bellows et al (1987) attributed 50.9% of calf mortality to dystocia (406 of 798 mortalities). In another study, calves that experienced dystocia were 13 times more likely to die within 12 hours of birth and 4 times more likely to experience a morbid incident by 45 days of age than calves that did not experience dystocia (Wittum et al, 1994a). Producers in the *Beef '97* survey reported a dystocia incidence in heifers of 17%. The prevalence of dystocia in heifers calving at 2 years of age commonly ranges from 15% to 30%, causing significant financial loss. Dystocia causes increased perinatal calf mortality, morbidity, and decreased productivity in cow-calf herds. Increasing incidence of dystocia in a herd has been associated with increased incidence of calf morbidity and mortality in the herd (Sanderson and Dargatz, 2000). Dystocia incidence above 20% was associated with a fivefold increase in risk for high herd morbidity and mortality. Dystocia has also been associated with an increased incidence of mothering problems in all age dams. Once the effect of dystocia was accounted for, no effect of dam age was noted (Wittum, 1994a). In addition, pregnancy rate may be decreased in the next breeding season in the females that lost calves (Patterson et al, 1987), and prolonged parturition may cause depressed subsequent reproduction in beef cattle (Doornbos et al, 1984).

Dystocia is of primary concern in primiparous beef replacement heifers. In one study, for every 1% increase in the percentage of heifers calved in a herd, risk for high herd calf mortality increased 1.2 times (Schumann et al, 1990). Dystocia management in replacement heifers must begin with proper replacement heifer development (see "Replacement Heifer Development"). Fetal pelvic size incompatibility is a major contributing cause of dystocia. Calf birth weight, the size of the pelvic area of the dam, and the interrelationships of these two factors are major determinants of dystocia (Meijering, 1984; Anderson et al, 1993b). While the role of birth weight in dystocia is well established and likely most important (Anderson et al, 1993b), the role of pelvic dimension is less clear (Van Donkersgoed et al, 1990). The weight of the calf is a function of genetic and environmental factors. Genetic factors include sex, length of gestation, breed, heterosis, inbreeding, and genotype. Nongenetic factors include age and parity of the dam, nutrition of the dam during various phases of gestation, and environmental temperature. Dystocia is likely a threshold trait; that is, dystocia is not related to birthweight in a linear manner. Once a certain threshold birth weight is reached in a herd, dystocia rates may increase dramatically. Conversely, after decreasing birthweight to a certain level, further decreases have only a minimum effect on dystocia rates (Anderson et al, 1993b). Genetics for high growth rate after birth are expressed prenatally, so selecting for decreased birthweight also may select for lower growth rate postnatally. For these reasons minimizing birthweight may not be cost effective. Increase of birthweight to the threshold for the herd to optimize dystocia rates and growth rate is likely the best practice.

Efforts to manage dystocia level and moderate its effects must center on replacement heifer development, sire selection, and early dystocia intervention.

TABLE 13-21

Calving Practices in the United States

Management Practice	
Percent of operations calving in special calving pastures	21.1
Percent of operations that observe calving heifers 3 times or more in 24 hours	44.3
Average number of hours heifers allowed to labor before assistance given	2.8
Percent of operations allowing heifers to labor 3 or more hours before assistance given	39.3
Average number of hours cows allowed to labor before assistance given	3.5
Percent of heifers requiring calving assistance	16.7
Percent of cows requiring calving assistance	2.7

BOX 13-11

Keys to Calving Management

Dystocia management
Passive transfer
Calving environment
Cow-calf pair management

Replacement Heifer Development for Dystocia Management

Dystocia rates in beef heifers cannot be reduced by nutritional restriction during late pregnancy (Kroker and Cummins, 1979). In controlled feeding trials the restriction of energy intake in the bovine female to a level that maintains maternal body weight has little influence on the development of the fetus, even though maternal metabolism may be altered considerably by the level of energy intake (Prior et al, 1979). Within certain experimental limits, the level of maternal dietary energy intake does not influence fetal weight or composition (Prior and Laster, 1979). However, the loss of 0.5 kg/day during the last trimester of pregnancy in beef heifers is associated with weak labor, increased dystocia rates, reduced calf growth rate, prolonged

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postpartum anestrus, reduced pregnancy rate, and increased morbidity and mortality (Kroker and Cummins, 1979; Corah et al, 1975). These are not evident in heifers that are maintaining or gaining weight at a moderate rate during late pregnancy. It is recommended that heifers be fed to allow modest rates of body weight gain (0.5 kg/day) during late pregnancy. Protein malnutrition in late pregnancy has been associated with weak calf syndrome and may be a factor contributing to neonatal mortality in beef calves. Beef cows fed 0.37 kg of crude protein/day during the last 4 months of pregnancy had a decreased gestation period of 274 versus 282 days and decreased weight gains compared with controls fed 0.96 kg (Waldhalm et al, 1979). Calf mortality in the low-protein group was caused by dystocia or prematurity. Cow weight and weight loss are functions of the interactions within a herd. Genetic background, breed of cow, management, amount and quality of feed, and degree of shelter provided during cold and windy weather all contribute to body weight loss.

Measurement of the pelvic area of the dam to predict dystocia is used as a criterion for the selection of replacement heifers, even though pelvic area alone has been shown to explain only a small proportion of the variability in dystocia (Johnson et al, 1988). Pelvic area measurements before the breeding season or at the time of pregnancy examination have been used to estimate the pelvic area before calving. Those heifers with a small pelvic area before the breeding season may then be culled or selectively mated to easy calving bulls, and those with a small pelvic area at the time of pregnancy examination may be aborted, culled, or identified for careful observation at calving (Deutscher, 1985). Some on-farm studies have reported that pelvic measurements a few weeks before the breeding season and again at the time of pregnancy examination have poor positive predictive values and sensitivities in each herd (Van Donkersgoed et al, 1990). Although the mean pelvic area in the heifers with dystocia was slightly smaller than for those without calving difficulty, there was a large overlap in the distribution of their pelvic areas. Reasons for the inconsistent results among different observations include the definition of dystocia, the accuracy and precision of the measurement procedure, and the fact that calf birth weight in relation to the dam's pelvic area determines the degree of calving difficulty (Van Donkersgoed et al, 1990). Some evidence suggests than culling heifers with the narrowest pelvic width may be more effective than culling based on pelvic area (Anderson et al, 1993b).

Sire Selection for Dystocia Management

The use of pelvic area measurement to decrease the incidence of dystocia without using some method of controlling or predicting calf size would be ineffective. However, a combination of culling heifers with small pelvic areas and using bulls that sire calves with small birth weights might reduce dystocia significantly (Makarechian and Berg, 1983). Using only the sires' birth weight to control calf birth weight and dystocia is not effective. A large number of nongenetic influences affect birth weight, such as age of the dam, environment, and birth type. The ability to identify sires appropriate for use on replacement heifers has advanced significantly in recent years. The use of expected progeny differences (EPD) for birth weight is more effective than using only sire birth weight in selecting for acceptable birth weights. EPDs are reported in the units of the trait that they reflect (e.g., pounds for birth weight). Along with each EPD is reported an accuracy ranging from 0 to 1. The accuracy is a measure of the reliability of the EPD value, a statistical confidence in how accurately the EPD reflects the true effect of the bull. Higher accuracies indicate a higher level of confidence that the stated EPD truly reflects the bulls' effect. EPDs are most effective at comparing bulls rather than identifying the specific effect a bull will have on a herd. For example, a bull with a birth weight EPD of +4.0 would be expected to sire calves 6 lb heavier on average than a bull with a birth weight EPD of −2.0 when bred to the same set of heifers. An attempt should be made to identify bulls with low birth weight EPDs for use on heifers while maintaining at least moderate weaning and yearling weight EPDs. This is best achieved by the use of AI sires with high accuracy EPDs. EPDs can be calculated on yearling bulls with no progeny based on their performance and their pedigree performance, but the accuracy is low. Distributions of EPDs and mean values can be obtained from the respective breed associations to assess the ranking of bulls within the breed. Until recently EPDs were only useful in comparisons within breeds. Methodology for across-breed EPDs have been developed to allow estimation of the effect of bulls on different breeds. This is of particular use in selecting bulls to control dystocia in crossbreeding programs. Currently, adjustment factors between breeds are available to assess the effect of a bull in a crossbreeding system (Van Vleck and Cundiff, 1998). Two recent innovations in the use of EPDs for management of dystocia are the calving ease EPD and the maternal calving ease EPD. Calving ease EPD is related to birthweight EPD but may predict calving ease more effectively. Maternal calving ease is a measure of the effect of the maternal grandsire and the ease with which a bull's daughters will give birth.

Multiple factors influence calving ease, likely including ones not yet known. Calf birth weight is the most important factor in dystocia (Naazie et al, 1989), accounting for 30% to 50% of the variability in dystocia rates (Meijering, 1984). As the birth weight of the calf increases, the incidence of dystocia also increases. Calves with an inherent ability for growth exhibit that genetic potential in utero, and, although this may produce birth weights capable of causing dystocia, it also causes superior weaning weights. Calving difficulty is higher for male than female calves (McDermott et al, 1992). Cows that calve unassisted generally weigh more at calving than those with difficult births. Abnormal presentations of the calf accounted for 22% of dystocias and 4% of all births in one study (Holland et al, 1993). Most dystocias occur in primiparous 2-year-old heifers, and the frequency decreases with increasing age and weight of the cow. At least some studies have suggested that cows that had previously experienced dystocia were more likely to experience a subsequent dystocia (McDermott et al, 1992). Environmental effects may also have an effect on calf birth weight and dystocia. Cold weather may increase birth weights and subsequently increase the incidence of dystocia (Burns et al, 1979).

Early Intervention for Dystocia Management

Despite the best efforts to avoid dystocia, some episodes will occur. Indeed, as discussed previously, minimizing dystocia incidence may not be an economically justifiable goal. Early intervention in dystocia cases will work to minimize the effects of dystocia on calves. Dystocia can cause hypoxia, acid-base disturbance, and decreased vigor, leading to a delay in ingestion of colostrum and increased incidence of failure of passive transfer. In one study, approximately one third of the anatomically normal calves that died in association with a difficult calving had not been given assistance but had gross pathological evidence of parturition injury. The authors suggested that these deaths could have been prevented if surveillance and obstetric assistance had been provided (Bellows et al, 1987). Research indicates stage II labor

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should not exceed 1 hour in heifers and 30 minutes in cows (Doornbos et al, 1984). This same study showed that heifers that complete stage II labor within 1 hour do not have extended postpartum intervals. Heifers will need to be monitored regularly and provided with assistance promptly if stage II labor is not to exceed 1 hour. Data from the *Beef '97* survey showed that 39% of heifers were allowed to labor for 3 or more hours before assistance was given (NAHMS, 1997a). If heifers cannot be monitored regularly, bull selection should focus on minimizing birth weight at the expense of growth. The individual herd will need to identify the most economical level of dystocia and growth and select a bull to match. Producers must be well trained to intervene appropriately in dystocia and must recognize when to call the veterinarian. A general rule of thumb for the producer is that if they have not made significant progress in delivering the calf within 30 minutes, it is time to get help.

Passive transfer in calving management

Calves receive immunity passively from the dam through the ingestion of colostrum. The calf's immune system is immature at birth and dependent on acquisition of passive immunity for disease protection in early life. Immunoglobulin (IgG1 and IgM) and lymphocytes are absorbed directly across the gut into the calf's circulation to provide immunity. The ability of the gut to absorb these large molecules and cells is a transient phenomenon. Gut closure is complete by 24 hours and absorption has decreased significantly by 6 to 8 hr of age. Ingestion of adequate amounts of quality colostrum as early as possible after birth is important for calf survival and growth. Limited surveys of beef calves have shown a passive transfer failure rate of 11% to 30% (Perino, 1997). Calves with failure of passive transfer (FPT) are three to nine times more likely to become sick before weaning, and five times more likely to die before weaning compared with calves with adequate passive transfer (Wittum and Perino, 1995; Perino et al, 1993).

The relationship between dystocia and FPT has not been consistent in the literature. In a set of 73 crossbred 2-year-old heifers, an increase in calving difficulty score was associated with decreasing serum IgG1 and IgM levels in calves even though assisted heifers were milked out and calves force fed (Odde, 1988). Increased calving difficulty was also associated with an increased interval from birth to standing. Other studies have not shown significant differences in immunoglobulin levels between calves experiencing dystocia and those not when both groups were force fed an equal amount of colostrum (Stott et al, 1978) or when allowed to suckle (Perino et al, 1995). Postnatal respiratory acidosis resulting from dystocia has been associated with decreased colostral absorption despite adequate colostral intake (Besser et al, 1990). It seems likely that dystocia would have some negative effect on passive transfer.

The relationship between prepartum nutrition and FPT has not been firmly established. In 2-year-old heifers, BCSs at calving did affect calf serum IgG1 levels. Calves from heifers calving with a BCS of less than 5 had lower IgG1 levels than calves from heifers with BCSs greater than or equal to 5 (Odde, 1988). Other studies have not found a difference in calf immunoglobulin levels after restricted nutrition in the final trimester (Hough et al, 1990) Heifers fed a restricted diet do have decreased colostral volume but increased IgG1 concentration (Odde, 1988). Numbers of animals in most studies have been small, perhaps limiting the ability to detect the effect of prepartum nutrition. Despite the lack of clarity in the relationship between prepartum nutrition and FPT, a well-balanced ration should be provided to prepartum cows and heifers.

Mastitis in beef cows has been associated with decreased serum immunoglobulin levels (Perino et al, 1995). Mastitis has not been studied extensively in beef cows; however, available studies have found a prevalence of 9% (Perino et al, 1995) to 32% (Simpson et al, 1995). Poor udder conformation in beef cows has been associated with increased time spent teat seeking and time to first suckle in calves (Ventorp and Michanek, 1992), perhaps increasing the likelihood of FPT.

Management to minimize the incidence of FPT should emphasize dystocia management, proper nutrition, and intervention with calves at high risk for FPT. Cows that experience dystocia should be milked out immediately and the calf force-fed colostrum to ensure ingestion. Cows with poor udder conformation or mastitis should be milked and the colostrum fed to the calf to ensure timely intake. Colostrum supplements have not proved useful in controlled clinical trials in elevating serum IgG levels (Perino et al, 1995; Mihura et al, 1997). Vaccination of the cow before calving with pathogens causing enteric disease in calves may be a useful adjunct to good overall management in reducing morbidity (Cornaglia et al, 1992; Boland et al, 1995). Vaccination in both studies caused approximately 50% decrease in morbidity, although blinding was not practiced so treatment bias cannot be ruled out. Vaccination of cows prepartum against IBR (Mechor et al, 1987) and BRSV (Belknap et al, 1991) protected calves against experimental challenge. For optimum effect cows should receive their final booster vaccination 2 to 3 weeks before the onset of calving season.

Management of the Calving Environment

Research data on the optimum management of the calving season at the herd level are sparse, perhaps because of the difficulty in assembling large numbers of cooperator herds to provide a statistical basis for inference at the herd level. One such study examined risks for high herd mortality level using 56 herds in a case control design (Schumann et al, 1990). This study found a number of univariate associations of management practices and herd mortality incidence. In the final multiple logistic regression model, percentage of heifers in the herd (odds ratio 1.2), poor drainage in the calving area (odds ratio 1.4), and wintering cows and heifers on the same ground (odds ratio 6.4), were associated with increased risk for high herd mortality. For every 1% increase in the percentage of poorly drained calving area, risk for high herd mortality increased 1.4 times. Calving of cows and heifers together was associated with increased herd mortality in a univariate analysis. It was highly correlated with wintering cows and heifers together and was not included in the final multivariate model. Increasing calving area was associated with increased herd mortality, but the odds ratio was very small (1.001) and not likely biologically significant. Similarly, providing shelter in the nursing area was associated with decreased herd mortality of questionable biological significance (odds ratio 0.998). Dystocia incidence was not collected in the study, and odds ratio estimates might change significantly if it were included as a covariate. Season of calving may be associated with morbidity and mortality levels as well, likely through weather stress. One Canadian study found calves born from December to March were four times more likely to die within 24 hours and two times more likely to have diarrhea from 1 to 30 days of age than calves born in April and May (Ganaba et al, 1995). Provision of shelters that allow calves protection from the weather may be useful in decreasing stress and morbidity (Olson, 1986); however, good data to support this are not available. Care should be exercised when shelters are used for calves, since they concentrate calves in a

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small area and may increase infection pressure. Movable shelters may be best to allow their removal from contaminated areas on a regular basis. It may be useful to provide access to the shelters during inclement weather and to restrict access during good weather to minimize the buildup of pathogens. Calving later in the spring has been advocated as a way to match cow nutritional needs to forage resources, decreasing the amount of harvested feed fed to cows, and feed costs. Such a plan may also be useful in managing calf morbidity and mortality. The moderate weather of late spring is less stressful on calves, requiring less provision of shelter and subsequent population density. Increased solar radiation and decreased wet and muddy conditions may decrease the buildup of pathogens, causing decreased calf exposure. In addition, more moderate temperatures may decrease birth weight and dystocia incidence (Burns et al, 1979). Fall calving can provide similar benefits as late spring calving in relation to calf morbidity and mortality. In the United States, 64% of calves are born in February through April and 9% of calves are born in June through September (NAHMS, 1997a).

The purpose of environmental control emphasizes decreasing calf stress and infection pressure on the calf. Unfortunately, these two goals are somewhat antagonistic. Controlling calf stress centers on close confinement and observation of calving to ensure prompt dystocia intervention and the provision of shelter from inclement weather for calves. Close confinement to facilitate observation and provision of calf shelter increases population density and subsequently infection pressure on the calf. Balancing these two competing interests to optimize the calf crop is the objective of calving management. Unfortunately, good data on where the optimum combination may be are scarce. Clearly, dystocia is an important, perhaps the most important, risk for calf morbidity and mortality. Calving in confined conditions appears to be associated with increased morbidity, but population-attributable fractions suggest it is less important than dystocia (Sanderson and Dargatz, 2000). Data on the optimum square footage necessary for each cow or heifer in the calving pen are not available. Estimates vary from 1000 to 2000 sq ft/cow in the observation pen. From an infection pressure standpoint, the more space provided, the lower the infection pressure; however, monitoring becomes more difficult as the area increases. Current knowledge of proper management of the calving environment suggests the key areas discussed in Box 13-12.

BOX 13-12

Management of the Calving Environment

1. Calve cows and heifers separately. This provides the opportunity for increased observation of first calf heifers to ensure prompt dystocia intervention. There may be effects of decreasing exposure of heifers to pathogens.
2. Calve cows and heifers on calving grounds separate from the wintering grounds. Moving to fresh ground for calving decreases the accumulation of pathogens in the environment. Ideally, calving grounds should be left vacant the rest of the year to allow drying and solar ultraviolet rays to decrease the pathogen levels. Pens should be scraped and allowed to dry over the summer.
3. Ensure that calving pastures are adequately drained to avoid standing water and mud and/or manure buildup. Pathogen accumulation and survival are increased by providing a moist environment, causing increased infection pressure on the calf. Preferably, calving pens should have a slight slope to encourage runoff of water and a compacted surface to minimize the amount of water that is absorbed. Calving pastures should have good grass cover to minimize mud and be managed to maintain the grass. All calving lots or pasture should have a southern exposure to facilitate drying and maximize solar radiation.
4. Manage dystocia pens to minimize pathogen buildup and infection pressure on calves. Pens used for dystocias or mothering problems should be easily cleaned and not supportive of pathogen buildup. Concrete floors are ideal for cleaning but may not be economically practical in many instances. Compacted sand or gravel may be a useful alternative. Sand and gravel support minimal bacterial growth and can be scraped and replaced between calving seasons. Pens should be bedded, with the bedding material being replaced between calvings. An adequate number of pens is necessary to allow for time to dry out after cleaning and before being used again.
5. Consider calving at a time of year when weather factors are least stressful on calves and the environment is easiest to manage. This recommendation requires a comprehensive plan for marketing calves and an assessment of the economic effects of the calving season change in all areas of the enterprise. Such a change should not be entered into in a cavalier way but may be indicated in some situations.

Cow-Calf Pair Management

Physical-spatial management of the pregnant cow or heifer and the postpartum pair is an important component of calving season management. Again, hard data on optimum practices are scarce. Some reasonable practices can be recommended, however (Box 13-13). See Fig. 13-9 for an example facility for management of calving groups.

The most common cause of calf morbidity in the neonatal period is diarrhea. According to a major survey of U.S. beef producers, 80% of morbidity from birth to 21 days of age is due to diarrhea (NAHMS, 1997b). It is generally not possible to differentiate diarrheas associated with different etiological agents based on clinical signs. The age distribution of infection for the common etiological agents associated with acute undifferentiated diarrhea are summarized in Table 13-22. The difference in the age of calves affected can be helpful clinically in identifying likely agents involved. Cows and calves often serve as carriers of the common agents of diarrhea in calves. Mature cows commonly carry *Rotavirus, Coronavirus,* and *Cryptosporidia* and shed them to the environment particularly around calving time. *E. coli* and *Salmonella* may be commonly introduced to a herd by the importation of a shedding animal. Once calves are infected on the farm, they become multipliers of the infectious agent, causing a rapid rise in environmental contamination. *C. perfringens* is a ubiquitous organism in the environment. Control for pathogenic agents of neonatal diarrhea involves segregation of sick animals from the healthy nursery in order to decrease environmental contamination and transmission. In addition, *E. coli* and *Salmonella* control involves biosecurity rules to prevent the purchase and introduction of new calves or cows during the calving season. Once calves are identified as sick, they should be isolated quickly to prevent further environmental contami-

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BOX 13-13

Physical-Spatial Management of the Cow-Calf Pair

1. Calve cows and heifers separately. This provides the opportunity for increased observation of first calf heifers to ensure prompt dystocia intervention. There may be effects of decreasing exposure of heifers to pathogens. For reproductive reasons heifers are often calved 3 to 4 weeks before the cows.
2. Calve cows and heifers on calving grounds separate from the wintering grounds. A move to fresh ground for calving decreases the accumulation of pathogens in the environment.
3. Two to three weeks before the onset of the calving season, cows and heifers should be moved from winter grounds to calving grounds.
4. Sort heifers and cows into management groups based on estimated calving date. This criterion for sorting can be provided from data collected at the time of pregnancy examination, when cows and heifers are grouped based on estimated gestational duration. Separation of the herd into management groups allows more concentrated observation of a smaller number of cows or heifers that are more likely to be calving and need intervention.
5. Ensure that cows and heifers accept and mother their calves. Heifers especially are at risk to reject their calves, subjecting them to increased risk for disease. If heifers do not accept their calves and allow nursing within a short time, they should be brought into the calving barn and restrained to allow the calf to suck. Heifers that experience dystocia and human intervention are at increased risk for rejecting their calves.
6. If cows or heifers experience difficulty in calving or mothering, move them to the calving barn for intervention and monitoring. Pairs entering the calving barn are at increased risk for disease because of dystocia, mismothering, or hypothermia and the exposure to the population dense environment of the barn. Once a pair enters the calving barn, they should not go to the general nursery pasture but to a separate high-risk nursery. Calves in the high-risk nursery can be monitored more intensively for morbidity and treated promptly. Segregation of these high-risk calves also avoids exposure of the rest of the herd.
7. Once cows or heifers have calved, move the pair out of the calving area to a nursery pasture within 24 hours. Once the pair has bonded and passive transfer has occurred, pairs should be moved to a nursery with decreased population density to minimize infection pressure.
8. Calves identified as morbid in the healthy nursery pasture should be removed and brought to the barn for treatment if necessary and placed in a morbidity nursery. Clinically ill calves can serve to multiply infectious agents and cause high levels of environmental contamination. One study suggested that quarantine of diarrheal calves and their dams from the rest of the herd decreased morbidity incidence.* The morbidity nursery may be combined with the high-risk nursery, but this will increase exposure of the high-risk calves to pathogens. Morbid calves should not be returned to the general nursery area.
9. Treatment equipment should be disinfected thoroughly between calves to avoid transfer of infectious agents from calf to calf.

*Clement JC, King ME, Salman MD, et al: *J Am Vet Med Assoc* 207:1334-1338, 1995.

nation of the healthy nursery. Once the environment is contaminated, moist cool conditions allow survival of infectious agents for an extended period. *Cryptosporidia* is especially suited to survival in the environment (Corwin, 1992), and prevention of contamination in the healthy nursery is especially important.

Commercial vaccines are available for *Rotavirus, Coronavirus, E. coli* K99, and *C. perfringens* types B and C. They are to be given to cows and heifers before calving to elevate specific immunoglobulin levels in colostrum. An initial vaccination and booster followed by a yearly booster vaccination is required. The booster vaccination should be given at least 2 weeks and not more than 6 weeks before calving. Clinical trial data are not consistent; some trials report no effect, whereas others report significant decreases in morbidity. Vaccination is likely a useful adjunct to proper management in controlling neonatal diarrhea. Vaccination does not lead to effective control when the level of management is poor. An oral modified live vaccine is available for administration to calves at birth. It must be administered at least 1 hour before colostrum ingestion. Clinical trial data have not supported its effectiveness.

The individual management of sick calves has been reviewed extensively elsewhere, and the reader is referred to those sources for recommendations on the treatment of individual calves (Radostits et al, 2000; Smith, 1996).

Veterinary Role in Calving Management

The veterinarian should be involved in designing and implementing management and environmental practices that control herd morbidity and mortality. The key areas and principles of management were summarized previously. If the opportunity arises to be involved in the design of calving facilities, these principles should be applied to design an optimum calving environment. Calving and nursery pens should be large enough to prevent buildup of pathogens and increased infection pressure. Proper drainage to avoid mud buildup in the calving or nursery pens is important. Drainage from the morbidity nursery to the calving pen or healthy nursery, or from the calving pen to the healthy nursery, should be avoided. Pens for assistance should be easily cleaned. Economic implications of recommendations should always be examined. An example of a calving facility is shown in Fig. 13-9.

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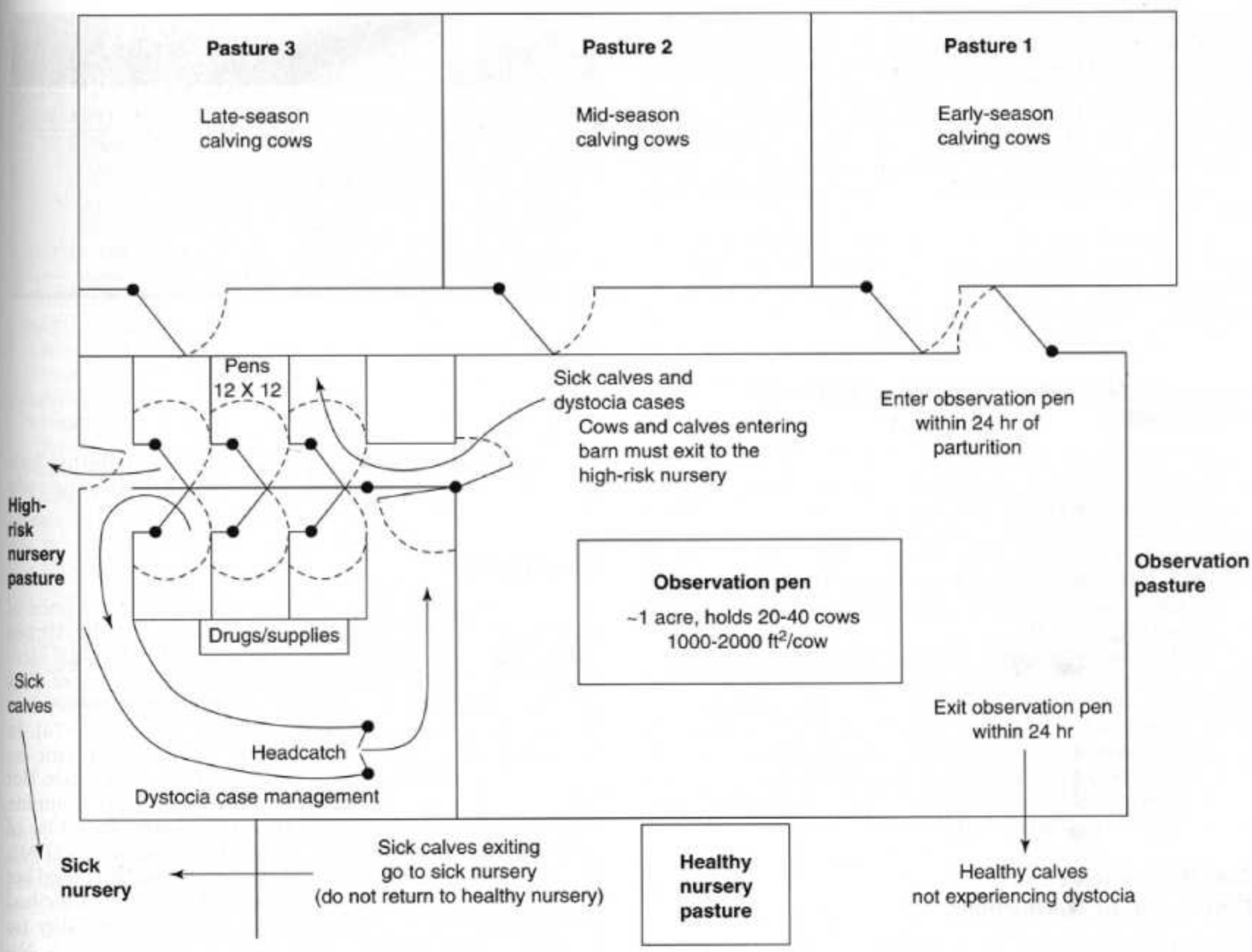

FIG. 13-9 Example of a calving facility.

The veterinarian should be able to assist the producer in selecting bulls to optimize calving ease and postnatal growth based on expected progeny differences. Ration formulation to provide proper nutrition is necessary for acceptable calving performance and subsequent calf health and performance.

A visit to the farm approximately 4 weeks before the onset to the calving season will provide the opportunity to evaluate the preparations made by the producer and to recommend any final changes. Proper dystocia intervention rules and procedures can be reviewed with the producer at this time, as well as rules for handling cow calf pairs after calving. Ideally, records on calving ease, and morbidity and mortality incidence will be kept to allow analysis of risks and risk groups. If an increased incidence of disease occurs, it will be easily detected and the management factors responsible more likely will be identified with good records. At least one additional visit should be made to the farm 2 to 3 weeks after calving has begun in order to assess the management and environment. The producer should be encouraged to contact the veterinarian promptly if any increased incidence of morbidity or mortality in the herd is noted.

TABLE 13-22

Age Occurrence of Common Enteropathogens Associated with Acute Diarrhea in Beef Calves

Enteropathogen	Age (days)
Enterotoxigenic *Escherichia coli*	<3
Rotavirus	5-15
Coronavirus	5-21
Eimeria sp.	>21
Cryptosporidium sp.	5-35
Salmonella sp.	5-42
Clostridium perfringens types B and C	5-15

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Morbidity and mortality incidence levels may be established above which the veterinarian should be called and a preliminary investigation begun. If computerized records on morbidity and mortality incidence are kept up to date, weekly incidence rates can be calculated to track a current measure of the effect of disease. If morbidity and mortality rates are indeed elevated, an investigation should be undertaken to identify the management factors contributing to the outbreak.

Calving management is a key area in controlling calf morbidity and mortality and optimizing the weaned calf crop (see Table 13-19). There are many opportunities for veterinary involvement in calving management that can be profitable to the producer and veterinarian.

BOX 13-14

Common Calf "Working" Tasks

Castration and dehorning
Identification (branding and tagging)
Implants
Vaccinations
Antiparasitics

CALF MANAGEMENT (BRANDING TO WEANING)

Whereas most calf mortality occurs before 28 days of age, the majority of growth occurs after 28 days. Management of calves to optimize growth during the summer grazing period is important to cow-calf productivity. Diarrhea remains an important cause of morbidity from 21 days of age to weaning, but infectious bovine keratoconjunctivitis (IBK) and respiratory disease become increasingly important at this time (NAHMS, 1997b).

The first opportunity to manage calves after calving occurs in many North American herds at the time of branding when the calves are aged 3 to 10 weeks. Cow-calf herds are then commonly turned out to summer pasture and not worked again until fall just before or at weaning time. Ideally, management practices implemented should be chosen to decrease morbidity and mortality or increase growth rate. Commonly recommended practices are listed in Box 13-14.

Calf Procedures

Castration and Dehorning

Castration of male calves in early life is likely to be less stressful to calves than castration performed later when testicular size is dramatically increased. In addition, early castration raises less concern about humane treatment. In the United States, 75% of producers that castrate calves do so by 3 months of age, but 25% of producers do not castrate any calves before sale. Large herds are more likely to castrate calves than are small herds (NAHMS, 1998b). A number of methods are available for castration, including the open surgical technique, the use of rubber rings, and the Burdizzo method. Calves castrated surgically initially exhibit more agitation compared with calves castrated with rubber rings, but both groups resume normal behavior soon after the operation is completed (Fell et al, 1986). U.S. producers most commonly castrate calves by open surgical removal of the testicles, with use of rubber bands next most common (NAHMS, 1998a). Castration of calves should be coupled with use of implants in the steer calves to improve weight gains.

Dehorning early in life is also less stressful than when performed later when horns have increased in size. In the United States, 28% of calves have horns and 62% of herds had at least one calf born with horns. Nationally, only 61% of horned calves were dehorned before leaving the ranch, and less than 50% of calves in south-central and southeast regions were dehorned before sale. Nationally, only 28% of horned calves were dehorned by 3 months of age, and 52% were dehorned after 5 months of age (NAHMS, 1997a,b) Horns are mostly a problem for the feeding period in which horned calves require more bunk space and may cause more bruising in penmates than in calves without horns. Such problems are best managed by polled breeding or early dehorning.

Identification

Individual identification of cows and calves is the basis of making selections based on performance. In the United States 52% of operations use no method of individual identification for calves, although herds with 300 or more cows were more likely to identify calves individually (78%) than herds with less than 50 cows (41%) (NAHMS, 1997a). In herds that did practice individual identification, plastic ear tags were the most common method in all sized herds. Hot iron branding and plastic tags were the most common methods of herd identification in U.S. herds, but 49% of herds used no method of herd identification (NAHMS, 1997a). Among herds with 300 or more cows, 90% used hot iron branding for herd identification. Branding as a method of identification is coming under increasing scrutiny for product quality and animal welfare reasons. The U.S. National Cattleman's Beef Association has supported a voluntary national cattle identification system to support value-based marketing. Commercial products are currently on the market that allow individual electronic identification. Such initiatives may eventually replace current identification systems.

Vaccination Procedures

Data on the effectiveness of individual vaccinations in decreasing calf morbidity and mortality are hard to obtain. According to NAHMS' *Beef '97* report, calves are not commonly vaccinated for respiratory pathogens from 21 days of age to weaning. The *Beef '97* data do not differentiate time of vaccination within this window of time, so it is impossible to know the frequency of administration at branding time as opposed to later in life. Calf vaccination practices in U.S. beef herds are summarized in Table 13-23.

Vaccines are available for viral (IBR, BVD, PI3, BRSV) and bacterial *(Pasteurella, Haemophilus)* respiratory pathogens. Residual passive immunity in young calves may limit the detectable antibody response to vaccination at an early age. Available evidence suggests that calves vaccinated at branding time will be sensitized to the antigens and respond with an anamnestic response when given a booster vaccine at arrival in the feedlot (Parker et al, 1993). Recommended vaccination programs include clostridial and viral respiratory vaccination at the time of branding. A number of "value-added" calf programs have been initiated, some of

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TABLE 13-23

Calf Vaccination Practices of U.S. Cow-Calf Producers

Vaccination	Percent of Producers	
	1-21 days of age	22 days to weaning
Clostridial ssp.	6.8	61.9
Infectious bovine rhinotracheitis	1.9	28.4
Bovine virus diarrhea	1.5	25.5
Parainfluenza 3	0.9	22.8
Bovine respiratory syncytial virus	1.3	24.5
Pasteurella ssp.	0.4	9.9
Haemophilus somnus	0.5	16.2
Moraxella bovis Infectious bovine keratoconjunctivitis	1.2	8.4

From NAHMS: *Beef '97*, Fort Collins, Colo, 1998, U.S. Department of Agriculture.

which require a vaccination program at branding time. No field trial data are available that assess the effect of vaccination at branding on the morbidity, mortality, or performance of suckling calves. Pneumonia incidence is typically low during the summer grazing period, and clinical effectiveness of a vaccination program against respiratory disease would likely be difficult to show. Primary sensitization to increase subsequent vaccination response preweaning may be the major benefit of such a vaccination program. A booster vaccination is often administered to calves before weaning for viral respiratory agents. Vaccination for *Pasteurella* has been recommended for inclusion in a preweaning or weaning vaccination program as well (Coffey et al, 1996). Available data suggest that calf buyers are willing to pay higher prices for calves that had undergone a preweaning health program (King et al, 1995, 1996, 1997). Unfortunately, field trial data on the effectiveness of respiratory vaccines in decreasing morbidity and mortality in weaned calves are lacking (Perino and Hunsaker, 1997). Field trials to evaluate the effectiveness of vaccination should include the following factors:

- Assessment of a clinically relevant outcome (morbidity, mortality, performance)
- Random assignment of calves to treatment and control groups
- Blinded assessment of clinical outcome (especially important for morbidity outcomes)
- Appropriate statistical analysis (correct application of statistical tests and control of herd clustering effects)

IBK is a significant problem in suckling calves, although control has proved to be difficult. Vaccination against IBK has shown variable results. Challenge with a homologous strain after vaccination may provide some level of control (Lepper, 1988), but challenge with a heterologous strain creates little protection (Smith et al, 1990). Some genetic resistance to IBK has been shown to occur in Hereford cattle with pigmented eyes (Pugh et al, 1986). In a Kansas survey, steer calves with a "bad eye" were discounted $8.35 and heifer calves $7.58/100 lb at market (Brazle et al, 1988). The face fly has been shown to be important in the transmission of this disease; therefore fly control is important, although difficult because the fly spends a limited amount of time on cattle. Dust bags and insecticide impregnated ear tags are only effective in reducing fly numbers by 50% to 70% (Mock, 1993). Feeding of a mineral supplement containing chlortetracycline (CTC) may decrease the incidence of IBK; however, the future use of feed grade antibiotics in food animals is in question. IBR may also cause ocular lesions or predispose calves to IBK (George et al, 1988). A proper vaccination program for IBR may be helpful. Table 13-24 outlines possible vaccination programs for calves.

Implant Strategies

Use of hormonal implants as a management practice for calves has been shown to increase weaning weights by 3% to 5% (Griffin and Mader, 1997). Economic returns are typically $5 to $10 for every $1 invested. Implants are available for calves over 45 days of age. Despite the clear value of implanting calves, the NAHMS *Beef '97* survey indicates that only a limited number of producers take advantage of this management technique. In the *Beef '97* survey 94% of producers reported that they did not implant replacement heifers and 82% reported that they did not implant any other calves (NAHMS, 1997b). Larger herds were more likely to implant both replacement heifer candidates and other calves than were small herds. Among herds of 300 or more cows, 29% implanted replacement heifers one or more times, and 59% implanted other calves one or more times (NAHMS, 1997b). All steer calves and heifer calves that are not candidates for breeding should be implanted. Implantation of heifers that may be kept for replacements is somewhat controversial. Fertility of implanted heifers may be decreased, but increased level of nutrition may overcome most of this depression. Heifers that may be replacement candidates should never be implanted before 45 days of age, and multiple implants should not be used. If calves are to be retained after weaning, they should be reimplanted to improve postweaning gains. Performance of implanted calves will be poor if adequate nutrition is not provided.

Parasite Control

The effect of treating for internal parasites in suckling calves has not been examined adequately. Egg burdens of calves are typically low at spring branding but may rise significantly by mid summer (Reinemeyer, 1997). Deworming of cows in late spring may cause increased weaning weights in calves (Boyd and Kniffen, 1992). Studies examining the effects of deworming calves only at branding have been few and results inconsistent, with some showing positive effects (Stacey et al, 1995) and others no effect (Stacey et al, 1997). Deworming of calves in addition to cows in late spring appears to confer minimal additional benefit (Stacey et al, 1996, 1997). Deworming of early weaned calves in mid summer caused a 10-lb increase in weaning weight in one study (Purvis et al, 1996).

External parasites of cattle are estimated to be an important cause of economic loss as well. Studies have generally shown a weight gain response of 10 to 20 lb in suckling calves (Quisenberry and Strohbehn, 1984) when fly control is provided, although not all studies agree (Gerhardt and

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TABLE 13-24

Calf Herd Health Program (Three Options)

Time	Plan 1	Plan 2	Plan 3
Late Spring (Branding Time)	Brand Castrate Dehorn 7-Way or 8-way* clostridial 4-Way respiratory (killed BVD, IBR) Implant (steers and late heifers)	Brand Castrate Dehorn 7-Way or 8-way* clostridial Implant (steers and late heifers)	Brand Castrate Dehorn 7-Way or 8-way* clostridial 4-Way respiratory (killed BVD,IBR) Implant (steers and late heifers)
Preweaning (at least 2-3 weeks before weaning)		7-Way or 8-way* clostridial booster 4-Way respiratory (killed BVD, IBR) *Pasteurella** *Leptospira** Deworm	7-Way or 8-way* clostridial booster 4-Way respiratory (killed BVD, IBR) *Pasteurella** *Leptospira** Reimplant (if calves are retained)
Weaning	7-Way or 8-way* clostridial booster 4-Way respiratory (MLV) *Pasteurella** *Leptospira** Reimplant (if calves are retained)	4-Way respiratory (MLV) *Pasteurella** *Leptospira** Reimplant (if calves are retained)	Remove cows from calves. Leave calves in familiar surroundings and do not work to minimize weaning time stress.

BVD, Bovine viral diarrhea; *IBR,* infectious bovine rhinotracheitis; *MLV,* modified live virus.
*Optional vaccines based on herd and regional risk level.

Shrode, 1990). The most common method for fly control is the use of insecticide impregnated ear tags. Maximum fly control probably requires application of two ear tags to each cow and calf. Cows are commonly the only animals tagged. With the widespread use of pyrethroid insecticides in ear tags, emerging resistance has become a problem. Alternation of insecticides from different chemical families has been recommended for control of emerging resistance. Resistant phenotypes decline rapidly when the pyrethroid exposure is removed (Krafsur et al, 1993). Current recommendations are to use organophosphate tags for 2 years followed by 1 year of a pyrethroid tag, forming a 3-year repeated cycle (Mock, 1993). Insecticide sprays and backrubbers can also be effective in controlling flies, but cattle must be forced to use them. Their use can provide the same level of control at a much-reduced cost compared with ear tags (Knapp and Webb, 1992; Sheppard, 1987). Application of pyrethroid sprays may select for fly resistance at a slower rate than use of pyrethroid ear tags (Sheppard, 1987).

Nutrition

Suckling beef calves are generally not supplemented during the summer grazing period, when milk and an increasing intake of forage provide their diet. Trace mineral deficiency may be a concern in some areas for calves. Proper trace mineral nutrition of the cow herd before calving provides the calf with adequate reserves at birth. Subsequent supplementation is difficult, since trace mineral mix intake is sporadic at best in calves. Creep feeding increases reliability of intake. Proper trace mineral nutrition is important for proper immune response.

Creep Feeding

Creep feeding in beef calves has been reviewed recently (Herd et al, 1998). Response to creep feeding has been highly variable, as has the economic return. Response is generally better when forage quality is decreased and calf gains are low. When forage quality and quantity are acceptable and cows are milking adequately, creep feed is an expensive substitute for available forage. When forage quantity or quality is limited, supplemental feed is used more efficiently by feeding calves than by feeding cows to produce milk for calves. Creep feeding causes decreased dry matter intake of forage, but milk consumption remains the same (Cremin et al, 1991). It may have a sparing effect on forage for use by cows but does not reduce lactation pressure on cows. Use of

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high protein, limited intake creep feeds can be efficient when forage is plentiful but of low quality. A summary of four studies using high-protein-limited feed creep on low-quality pasture showed a feed conversion of 2.6:1 (Herd et al, 1998). Consumption of high-protein-limited creep feeds should be controlled to 0.5 to 1 lb/head/day by mixing with salt. Creep feeding of potential replacement heifers should be avoided. Increased preweaning gains in heifers cause excess fat deposition in the udder, decreasing functional mammary parenchyma. Heifers appear to be most sensitive to the effects of fat deposition in the udder from 3 to 8 months of age. From 3 to 8 months of age, heifers gaining 2 lb/day showed decreased milk production and decreased calf-weaning weights compared with heifers gaining 1.2 lb/day. The result is cows with decreased milk production, decreased weaning weights, and decreased productivity (Johnsson and Obst, 1984).

The effect of creep feeding of calves on cow performance has been quite variable. Most studies have not shown a significant effect of creep feeding on production measures of cows the following year. Creep feeding for 3 to 4 weeks before weaning may be an effective way to reduce stress and disease at weaning. Calves will be acclimated to feed, achieve acceptable intakes quicker, and perhaps experience less morbidity from decreased stress at weaning. Small frame calves may show a depression in feed efficiency after weaning following creep feeding. Large-framed calves generally do not show depressed feedlot efficiency (Herd et al, 1998). Creep feeding may allow more calves to achieve choice quality grade by 14 months of age (Faulkner et al, 1994). It may have a sparing effect on BCS of cows and the amount of supplemental nutrition needed to get cows in adequate condition by calving.

Weaning

Weaning time is a particularly stressful time because the calf is removed from its mother and forced to adjust to a different diet; population density is increased, leading to potential for increased disease exposure and transmission. Management procedures should aim to minimize stress on calves while ensuring they are in sound condition nutritionally and immunologically. Proper cow-herd nutrition is important for the calf to begin its new life with adequate nutritional stores. By mid summer, calves are obtaining an increasing amount of feed from forage and may be consuming a limited amount of a trace mineral mix. A quality trace mineral mix should be available continuously for the cows and calves. Management practices that increase the stress on the calves should be minimized at weaning time. Castration and dehorning certainly should be performed well before weaning time. Ideally, vaccinations will be given before weaning to prepare the calf's immune system for increased exposure. Vaccinations given at weaning do not provide immunological protection during the period of highest risk immediately after weaning. In addition, immune response may be limited by the stress associated with weaning time. Completion of vaccination, deworming, and implant procedures before weaning allows calves to be weaned without handling. This serves to remove the stress of working through the chute and provides time for calves to respond to vaccinations before weaning.

Early Weaning

Early weaning of beef calves may be implemented when calves are 30 to 170 days of age. It may create more efficient use of feed resources by directly supplementing calves to maintain weight gain rather than supplementing cows to produce milk for calf growth. Weaning times as early as 30 to 60 days can increase reproductive performance of cows and heifers. Cows and heifers cycle and rebreed earlier in the calving season, and pregnancy rates are higher in a limited breeding season after early weaning at 30 to 60 days (Lusby et al, 1981; Guyer, 1983). Management requirements are increased greatly in calves weaned at this time. Nutritional needs of the weaned calves must be met carefully to ensure acceptable health and performance. When properly managed, postweaning weight gain of calves weaned at 30 to 60 days of age can equal the preweaning weight gain of calves weaned at 7 months of age (Lusby et al, 1981). Creep feeding the weaning ration to early weaned calves before weaning may be helpful to ensure early consumption after weaning. The postweaning ration should be balanced carefully to provide adequate nutrition to the calves. The final ration should provide 15% protein and 75% TDN and be balanced for vitamins, macrominerals, and microminerals.

Early weaning at 150 to 170 days of age decreases lactational stress on cows when forage resources are limited and causes improved cow condition. Reproductive performance in the breeding season is not affected by weaning at this time. When forage resources are limited, weaning calves to decrease the nutritional requirements of the cows will allow them to regain condition before winter with less or no supplementation. Calves can be supplemented more efficiently than cows. Depending on forage resources, feed costs, and market prices, early weaning may be an economic management consideration. Marketing of the calves should be thought out in advance. Direct marketing at early weaning would generally not be profitable, so plans should be made to retain calves and feed them until normal weaning time and weight (Table 13-24).

REPLACEMENT HEIFER DEVELOPMENT

Replacement heifer development programs generally commence at weaning as the heifers begin preparation for the breeding season. However, decisions relating to use of hormonal growth promoting implant programs for replacements must be made beginning at the spring working of calves at 2 to 3 months of age. Use of growth-promoting implants in heifer calves before 30 days of age may have severe effects on development of normal uterine function (Bartol and Floyd, 1996) and should not be practiced. Products are available for use in replacement heifer prospects from 45 days of age to weaning. Implants have been shown to increase weaning weight and frame score in heifers compared with nonimplanted control heifers. Pelvic area is increased in implanted heifers at 1 year of age, but most of the advantage over nonimplanted heifers is lost by calving and there is no difference in calving ease. The effect of implanting replacement heifers on their subsequent reproductive performance has been variable. In a review of the effect of implants on heifer fertility, application of a single implant caused an average depression in yearling pregnancy rate of 1% (range: +7% to −14%). Application of two or more implants caused pregnancy rate depressions as high as 42% (Deutscher, 1994). Some of the depression in pregnancy rate may be overcome by ensuring implanted heifers have sufficient nutrition to support a higher rate of gain (Deutscher, 1994). In general, reimplanting heifers at weaning, or after 6 months of age, is not recommended.

Heifers that calve at 24 months of age have increased lifetime production compared with heifers that calve first at 30 or 36 months of age. Heifers calving at 24 months of age produce an additional calf over their productive

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lifetime compared with heifers calving at 36 months of age (Lesmeister et al, 1973). Lehman et al (1993) used marginal cost analysis to assess the economic effects of calving *Bos taurus* heifers at 24 or 30 months of age. They calculated increased costs of calving 24-month-old heifers, including increased feed, increased dystocia and subsequent mortality, and decreased conception rates and weaning weights. This study found a $61/head advantage to calving heifers at 24 months of age even without including increased opportunity and inventory costs of calving heifers at 30 months of age (Lehman et al, 1993). When replacement heifers are managed properly, calving at 24 months of age is economical. Calving *Bos indicus* heifers at 24 months of age is possible but more difficult to achieve than with *Bos taurus* heifers and may not always be an economic proposition.

Heifer Selection

Selection of replacement heifer prospects begins at weaning time when the heifers are typically 6 to 8 months old. Selection at this point is based on birth date, conformation, frame score, and dam production records. Selection of heifers born early in the calving season leads to replacement heifers that are older and heavier at the start of the breeding season. Puberty is an age- and weight-dependent characteristic, so older heifers more easily reach target age and weight by breeding and nutritional supplementation cost may be less.

Conformation of replacement heifers is important for longevity of the cow herd. Heifers that remain in the herd longer have more productive years and provide increased return on their development costs. Heifers should be evaluated for conformation of their feet, legs, and udder. Unacceptable conformation in any of these areas should disqualify a heifer as a replacement prospect. Age-adjusted frame score can be used to estimate the mature size of prospects. It places some objective criteria on the selection of replacements to maintain a constant cow size designed to fit the environment and feed resources. Retention of the largest heifers each year causes the average cow size in the herd to increase over time. In addition, some evidence suggests that increasing weaning weights in heifers is associated with decreasing weaning weights in their offspring (Johnsson and Morant, 1984). As described in the section on summer calf management, average daily gain (ADG) of 2 lb in Hereford heifers before weaning may cause decreased milk production, although subsequent fertility may be improved (Johnsson and Obst, 1984). If available, dam production records can be used to select heifers from highly productive cows. However, in a study of cow-calf producers in the northwestern United States that regularly used a veterinarian for herd work, only 23% of herds kept cow-family production records (Sanderson and Gay, 1996).

Once potential replacement heifers are selected at, or after, weaning, a nutrition and vaccination program should be instituted in preparation for breeding. The design of the nutritional program depends on the breed and weight of the heifers and the time available before breeding. If heifers are to calve by 24 months of age, they must be bred by 15 months of age. This establishes the time available to prepare heifers for breeding. For optimum fertility heifers should weigh approximately 65% of their mature body weight by 12 to 13 months of age. Pregnancy rates are generally poor if heifers are bred on their puberal estrus, but they are significantly better when heifers are bred on the second or third estrus. For this reason, heifers should be developed to reach puberty at least 3 to 6 weeks before the breeding season. A ration must be balanced to provide the required rate of gain to meet the target goal of 65% of mature body weight in the time available. Specific requirements vary with the weight and breed of the heifers and the amount of time available before breeding. However, target or critical mating weights have been established for different breeds based on optimum growth rates (Table 13-25). Such lists should be used with caution because strong genotype-environmental interactions occur. However, to achieve such weights for breeding as yearlings requires target gains of 1 to 1.5 lb/day (0.5 to 0.7 kg/day). Periodic weighing of the heifers is useful to ensure that gains are progressing at an acceptable rate and allow for needed adjustments.

Excessive weight gains over the prebreeding period can be detrimental to heifer fertility (Utter et al, 1994; Minton et al, 1994). Recent evidence suggests that maintaining heifers at a low rate of gain for the first two thirds of the development period followed by a high rate of gain for the last one third may be more cost efficient. Heifers that gained 0.1 to 0.5 lb/day over the first 112 days of the development period followed by 2.4 to 2.8 lb/day for the last 56 days had similar reproductive performance as heifers that gained 1.1 to 1.3 lb/day over the entire development period (Lynch et al, 1997). The goal of the nutritional program is to develop fertile heifers that will breed early in their first breeding season. Heifers that calve early in their first calving season have greater lifetime production than heifers that calve late (Lesmeister et al, 1973).

Incorporation of ionophores into rations for replacements can decrease age and weight at puberty and decrease the feed:gain ratio (Purvis and Whittier, 1996). They have no effect on fertility of replacement heifers but may cause increased pregnancy rates in the first 20 days of the breeding season because of increased numbers of heifers exhibiting estrus. Ionophores can be included at 200 mg/head/day from weaning to breeding but will not be useful if the heifer ration is not balanced to provide a gain of approximately 0.75 lb/day (Floyd et al, 1995).

The effect of exposing heifers to bulls before breeding has been inconsistent (Roberson et al, 1987, 1991) but may decrease age at puberty. Heifers with an increased rate of gain may be more responsive to the effect of bull presence (Roberson et al, 1991).

TABLE 13-25

Target or Critical Mating Weights of Heifers

Breed	Weight (lb/kg)
Hereford	600-650/272-300
Angus	575-650/260-300
Shorthorn	575-650/260-300
Hereford × Angus or Angus × Hereford	600-625/272-285
Charolais crosses	675-725/310-325
Simmental crosses	650-700/300-320
Limousin crosses	650-700/300-320
South Devon crosses	625-675/285-310
Brahman crosses	700-750/320-350

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Reproductive tract scoring (RTS) systems have been developed to assess the maturity of the reproductive tract in heifers (Anderson et al, 1991). They are typically performed 30 to 60 days before the breeding season. The score is based on the size and tone of the uterus and the size and structures on the ovaries. Heifers with more mature tracts have increased pregnancy rates to synchronization than heifers with immature tracts. In one survey of well-developed replacement heifers, culling rate for immature reproductive tracts was very low (8 of 1489), suggesting the technique may be of limited use in properly developed replacement heifers (Spire and Holtz, 1995). It may be useful in late maturing or underconditioned replacement heifers to assist in culling heifers that will be unlikely to respond to synchronization (Spire, 1997), thus saving drug, semen, and labor costs.

The pelvic area of replacement heifers is commonly measured at 30 to 60 days before breeding. Pelvic area is not an effective predictor of future calving difficulty. On-farm studies have reported that pelvic measurements a few weeks before the breeding season and again at the time of pregnancy examination have poor positive predictive values and sensitivities in predicting dystocia (Van Donkersgoed et al, 1990). Mean pelvic area in the heifers with dystocia was slightly smaller than for those without calving difficulty, but there was a large overlap in the distribution of their pelvic areas. Pelvic measurement of replacement heifers is likely most useful for identifying heifers with small or abnormally shaped pelvises for culling. Minimum pelvic areas for yearling heifers of 150 cm^2 (Larson and Moser, 1998) and 160 cm^2 (Spire and Holtz, 1995) have been suggested as a culling criterion. Selection for increased pelvic area also leads to selection for increased mature cow size and increased birth weight. This effect can be minimized by using frame scores for selection criteria to stabilize cow size.

Heifer Vaccination Program

The vaccination program for replacement heifers should be designed to provide them optimum protection from reproductive diseases. Pathogens for which vaccinations exist, and estimates of the percent of heifers vaccinated, are summarized in Table 13-26. Vaccination for reproductive pathogens is common in herds in which a veterinarian is involved in management (Sanderson and Gay, 1996) but are considerably less common in a random sample of U.S. herds (NAHMS, 1998a). The program should include vaccination for *Brucella abortus*, IBR, BVD, *Campylobacter*, and *Leptospira* (Table 13-26). *Brucella* vaccination is carried out according to state or provincial regulations. Modified live vaccines for IBR and BVD may give the broadest immunity to strain differences especially for BVD. Modified live IBR and BVD should be given twice to ensure a high level of immunity. Some evidence suggests that modified live BVD and IBR may transiently infect the ovary and cause decreased fertility. For this reason, the second vaccination should be given at least 1 month before breeding. A vaccine containing *Campylobacter fetus* and five strains of *Leptospira* is given twice before breeding. Vaccination of heifers with *Trichomonas* vaccine has been shown to increase calving rate and decrease duration of infection in infected herds, but it does not prevent infection (Kvasnicka et al, 1992; Hudson et al, 1993). A vaccine for trichomonosis may be useful in infected herds or herds that are at high risk for infection, but it may not be economical in herds in which risk for infection is low.

Once the heifers are nutritionally and immunologically prepared for breeding, a synchronization program can increase the number of heifers that are bred early in the breeding season. In addition, AI allows the use of high-quality bulls with high-accuracy EPDs for birth weight. It is generally recommended to begin breeding heifers 3 to 4 weeks before the cow herd. This allows the heifers to calve early, be more closely observed, and have additional time to recycle and rebreed with the cow herd for their second calf. Advance planning is necessary to ensure adequate time to follow synchronization protocols before the desired breeding date. The heifer-breeding season should be limited to 45 to 60 days to place some selection pressure on early fertility and provide pregnant heifers with a reasonable chance to rebreed with the cow herd the following year. In synchronized herds, each heifer can have three opportunities to be bred in a 45-day breeding season.

Nutritional development needs to continue through the second breeding season. Heifers should be managed separately from cows until after they are bred for their second calf. Target weight for the first calving is 85% of mature body weight. Heifers that calve below target weight and in poor BCS have a longer postpartum interval, and lower pregnancy rates, and postpartum weight gain does not completely overcome this depression (Bell et al, 1990). Nutritional management from first breeding to second breeding is critical to optimizing the number of heifers that remain in the herd as productive cows. In herds in which replacement heifer development is suboptimum, heifers drop out at a high rate after their second breeding season and before the cost of developing them has been recaptured.

Commercial replacement heifer development enterprises are available to cow-calf producers. These development centers provide custom heifer development or development of heifers for sale. If the level of labor, management, or resources precludes proper heifer development, custom

TABLE 13-26

Replacement Heifer Vaccination Rates in the United States

Vaccine	NAHMS (%)*	Sanderson and Gay (%)†
Bovine viral diarrhea;	16.3	76
Infectious bovine rhinotracheitis	16.8	60
Parainfluenza 3	13.1	—
Bovine respiratory syncytial virus	12.1	—
Brucella	24.7	62
Leptospira	18.0	81
Campylobacter	11.0	79
Trichomonas	0.2	13

*From NAHMS: *Beef '97*, Fort Collins, Colo, 1998, U.S. Department of Agriculture.
†From Sanderson MW, Gay JM: *J Am Vet Med Assoc* 208:488-491, 1996.

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heifer development may be an economical alternative. Selected heifers may be sent to the development center for nutritional and immunological development and for breeding. Heifers are generally returned to the herd after breeding. For herds involved in a terminal sire-breeding program designed to produce slaughter calves, development centers may provide a source of quality heifers for replacement. Similar to bull test programs, replacement heifer development test programs are being developed by state beef improvement associations and university extension (Table 13-27).

Calving as Two-Year-Olds

The advantages of calving 2-year-old heifers include improved lifetime efficiency of 2-year-olds versus 3-year-olds, reduction of age of cows at culling through an overall reduction of herd average age, more effective use of pasture with all age groups contributing to net reproductive rate, and increased genetic progress in the herd for those characteristics under selection through generation intervals. Reasons given by some producers for not adopting 2-year-old calving compared with 3-year-olds include a greater incidence of dystocia, rearing of lighter calves, reduced reproductive performance subsequent to their first calving, and lighter weights when culled for age at 8 to 10 years of age. These particular reasons against 2-year-old calving are no longer valid. The major causes of dystocia are understood and can be managed practically and economically, the lighter weight of calves reared is not significant, and subsequent fertility is not reduced if heifer breeding is managed adequately. The lifetime calf crop from 2-year-old calvers can be expected to be equivalent to an extra 0.7 calf compared with 3-year-old calvers.

Heifer Breeding Management Models

A model has been developed for heifer breeding management (Mossman and Hanly, 1977). Here, a herd of 100 well-grown cycling heifers in excellent body condition is mated to proven bulls at a bull-to-female ratio (BFR) of 1:33 for 105 days. It is proposed that each 21 days, 60% of eligible heifers become pregnant. The theoretical conception rate in 100 heifers over 105 days is shown in Table 13-28.

The total number of services required to get 100 beef heifers pregnant at a 60% conception rate is 164—that is, 1.64 services/heifer. It takes 105 days to get 100% heifers pregnant. If breeding is terminated at Day 42, 84% are pregnant; at Day 45, 85% to 86% are pregnant. Another 60 days are required to get the remaining 14% to 16% in calf.

If the veterinarian assumes 100 days are needed after calving for an average first-calf heifer to return to heat, then the time to the second breeding (second breeding year) is 380 days (280 + 100). When the heifer returns to heat, she requires 1.64 services, on average. Therefore, for a heifer to become pregnant again, another 0.64 of a service, or 0.64 of a 21-day cycle, is required—13.4 days. The time of the first conception to the second conception (the calving interval) is now 393.4 days (280 + 100 + 13.4). Therefore the average heifer takes 393 days from first conception to second conception, which means that she is 28 days behind starting her lifetime production of one calf/cow/year. Thus, theoretically, heifers should be bred 28 days ahead of cows.

The theoretical heifer calving pattern over 105 days (in 21-day periods) is shown in Table 13-29 and Fig. 13-10.

If the heifers are first bred at the same time as the mature cows, the average calving interval will be 393 days. From the 100th day after calving, it takes 105 more days (Table 13-23) to get all the heifers pregnant again—a period of 485 days (280 + 100 + 105). It is impossible to get heifers pregnant again (within 365 days) that were not pregnant by the 62nd day of their first breeding period, because the calving index is greater than 455 days. If a mating period of 63 days is planned for the herd, then heifers not pregnant by the 45th day of their breeding period do not become pregnant during the herd-breeding period. This theory for reproductive failure is the basis of a limited heifer-mating period (42 to 45 days) 28 days ahead of the cow herd, in which a minimum of

TABLE 13-27

Replacement Heifer Health Program

Management	Management Procedures
Weaning	If vaccines boostered and dewormed preweaning, no procedures performed at weaning time
30-45 Days after weaning	Weigh, assess rate of gain and adjust ration as necessary Brucella vaccination
60-75 Days after weaning	Weigh, assess rate of gain and adjust ration as necessary Vaccinate Modified live IBR, BVD *Campylobacter* 5-way *Leptospira*
30-60 Days before breeding	Weigh, assess rate of gain, and adjust ration as necessary Pelvic measurement Reproductive tract score Vaccinate Modified live IBR, BVD *Campylobacter* 5-way *Leptospira*

BVD, Bovine viral diarrhea; *IBR,* infectious bovine rhinotracheitis.

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85% of heifers are pregnant and pregnancy-tested 6 to 8 weeks after the end of the breeding period. The use of real-time ultrasound for pregnancy testing is highly accurate as early as 26 to 28 days of pregnancy, and it could be used to test much earlier than 6 to 8 weeks after the end of the breeding period. The remaining 15% are the animals potentially not pregnant, and these could be culled and sent for slaughter. This would depend on current and predicted market prices and on the availability and costs of feed.

The calving pattern for the remaining 85% of heifers from the 100 heifers that were examined for pregnancy 6 to 8 weeks after mating is shown in Fig. 13-11.

If the postpartum interval for first-calf heifers could be shortened to 80 or 90 days using good prepartum and postpartum nutrition, it would cause increased conception rate as well as a concentrated calving season and pattern, which are all highly desirable. With a concentrated breeding period, heifers can calve in the spring on selected calving grounds with more control over feed intake before and after calving. This leads to large savings in feed, which is virtually impossible with a 90-day calving period. Another major economic advantage of concentrated calving is that the labor and surveillance required at calving time can be intensified and thus be more effective. It is more cost effective and beneficial to be watching several animals calving through the night than it is to watch one animal every night or every other night for 90 days.

Replacement Heifer Management

In order to optimize lifetime production, calving heifers at 2 years of age have become a widely accepted practice among beef producers. If a heifer is to calve at 24 months of age, she must be cycling and fertile at 15 months of age. However, many 15-month-old heifers have not reached puberty. Puberty in heifers is influenced by age, growth rate, breed, and level of nutrition. Age at puberty, date of conception, and conception rate are largely determined by the management of heifers during the winter period immediately after weaning. Reproductive performance is enhanced if heifer calf replacements are fed to gain weight at a rate of at least 0.5 to 0.75 kg/day from weaning to breeding so that they reach target weight. Thus replacements should gain approximately 100 kg from weaning to breeding. Winter weight gains may be more beneficial than gains during the breeding season (Lemenager et al, 1980). Where approved for use, ionophores such as monensin and lasalocid in the diet of heifer replacements fed harvested forage increase weight gain and improve feed efficiency (Sprott et al, 1988). Ionophores do not alter fertility but may decrease age at puberty in the female (Sprott et al, 1988).

A management system for replacement heifers from weaning through breeding is shown in Box 13-15.

Heifers should be well developed at the time of first breeding, and their management during gestation must ensure their continued growth. Pregnant heifers should be separated from the main cow herd at the time of pregnancy testing after their breeding season and maintained separately until reentry into the breeding herd after their first calving. This ensures that adequate nutrition and management levels are met. Such management may increase calf birth weight, but most of the increase is in soft tissue and skeletal structure and should be more than offset by the increased size and vigor of the heifers. Sires used with year-

TABLE 13-28

Theoretical Conception Rates in 100 Heifers over 105 Days

No. of Days After Calving	No. in Heat (%)
FIRST-CALF HEIFERS	
80	60-70
90	70-80
100	80-95
MIXED-AGE COWS	
80	80-89
90	90-94
100	95-100

Mossman DH, Hanly GJ: *NZ Vet J* 25:96-100, 1977.

TABLE 13-29

Theoretical Calving Index for 105-Day Second Breeding

Gestation Length (Days)	Days After Calving	Cycle of Breeding	60% Conception	Calving Index
280	100	21	13	414
280	100	42	13	435
280	100	63	13	456
280	100	84	13	477
280	100	105	13	498

Mossman DH, Hanly GJ: *NZ Vet J* 25:96-100, 1977.

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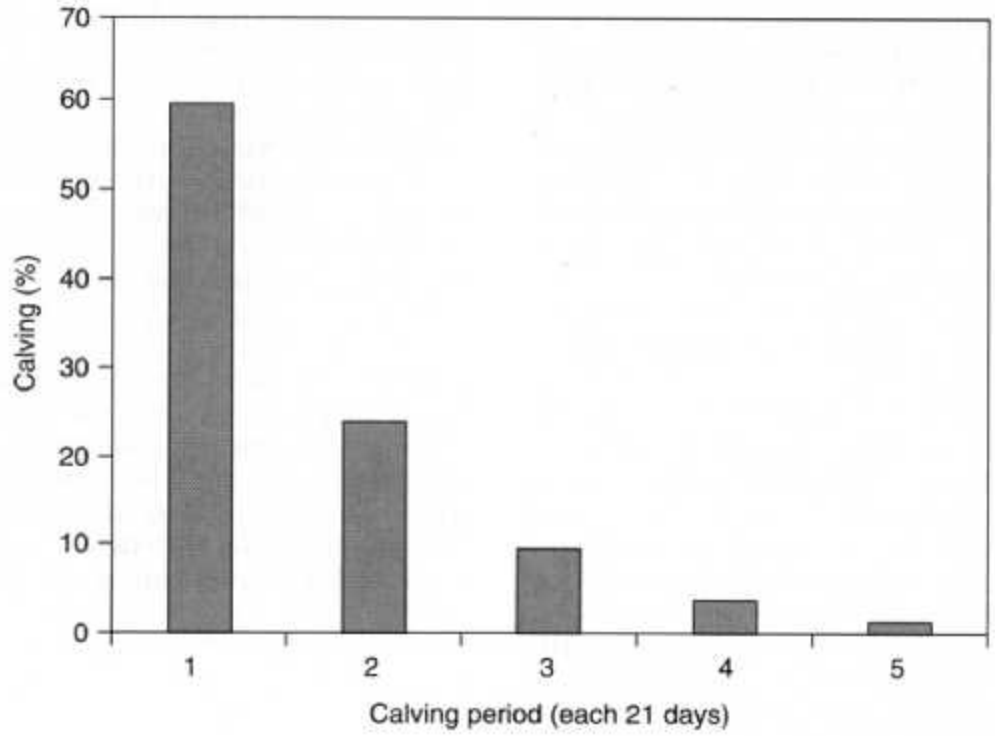

FIG. 13-10 Theoretical calving pattern for heifers.

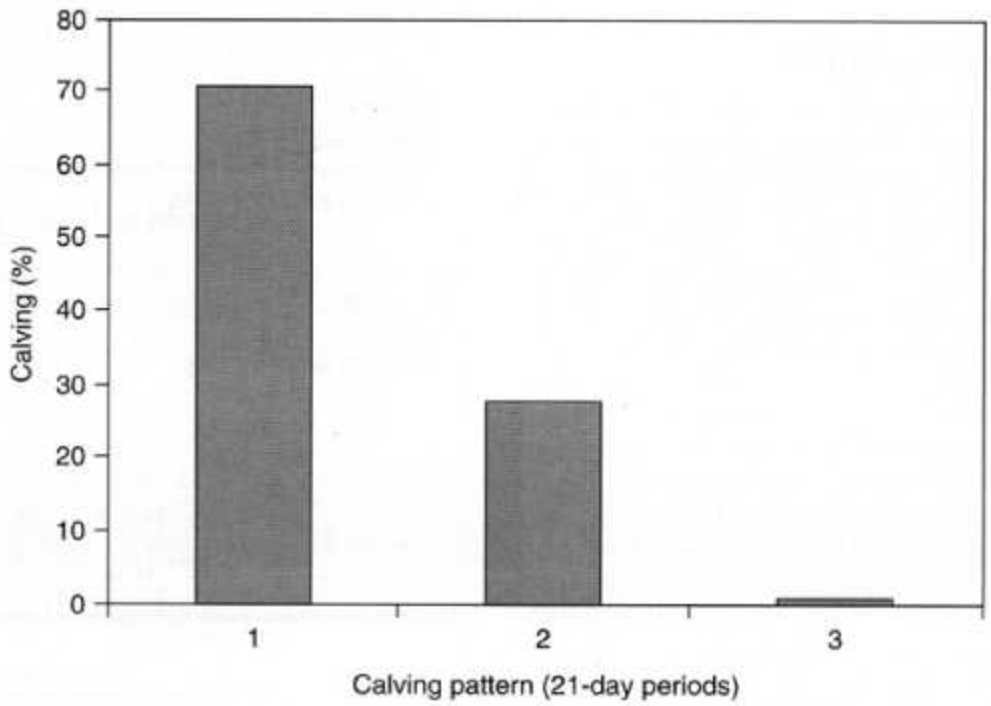

FIG. 13-11 Calving pattern for heifers examined for pregnancy 6 to 8 weeks after breeding.

ling heifers should be selected to minimize the probability of excessive birth weights when combined with the genetic makeup of the heifers. If close supervision is practiced at calving, a bull should be selected based on calving ease, but the same breed should be used as that used on the cow herd. If the heifers are calved on the range with minimum supervision, a breed of bull should be chosen to minimize calving problems. If there is any doubt about the heifer's ability to calve unassisted or if calving seems prolonged, obstetric assistance should be provided as soon as possible to minimize calf and dam injury, possibly death, and the problems of subsequent reproductive performance. Heifers should be bred ahead of the main cow herd. This ensures that any increase in the postpartum anestrus period after their first, perhaps difficult, calving does not compromise their chances for cycling and rebreeding with the main cow herd.

Maternal Nutrition and Subsequent Performance

Nutritional management of the beef herd is the main limiting or controlling factor for reproduction. Insufficient energy intake resulting from dietary quality or quantity delays puberty, lengthens postpartum anestrus, and causes anestrus in cows or heifers that are having estrous cycles (Short and Adams, 1988; Richards et al, 1989a,b).

The effect of winter weight loss in beef cows on subsequent reproductive performance has been documented

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BOX 13-15

Management System for Replacement Heifers

1. Select the largest and oldest heifers, and select 20% to 30% more than required. The largest heifers may be older and reach puberty quicker, they are probably faster growing, their dams were probably good milk producers, and they are easier to get to breeding weight. Selection of 20% to 30% more than required allows some culling for quality, development, pregnancy, and production. A guiding principle is to "select on performance and cull on fertility."
2. Feed heifers from weaning through to breeding for them to gain 0.5 to 0.75 kg/day. They should continue to gain weight throughout the breeding season. Weighing calves at weaning and subtracting weaning weight from the target breeding weight allow an estimate of the ADG required to reach the critical minimum weight for breeding to be made.
3. Vaccinate heifer replacements for those diseases that can cause abortion (e.g., infectious bovine rhinotracheitis, vibriosis, and leptospirosis), depending on the occurrence of these diseases in the area.
4. Provide suitable and permanent identification.
5. Weigh heifers 3 weeks before breeding to determine the critical minimum, or target, weight. The weights shown in Table 13-25 are those established for different breed types (all *Bos taurus*) of well-grown heifers to reach puberty in a temperate climate.

Excessive weight loss in 2- and 3-year-old cows causes delayed onset of estrus after calving and an increase in the percentage of nonpregnant animals and late calvers. Mature cows may reproduce satisfactorily on diets that are unsatisfactory for younger cows. Thus young cows respond favorably when fed a diet higher in energy than that fed to cows (Davis et al, 1977).

The nutrition of the pregnant beef cow, particularly the first-calf heifer, can have a marked influence on the subsequent reproductive performance of the cow and on the viability and health of the calf from birth to weaning. Undernutrition during pregnancy in first-calf heifers commonly leads to an increased incidence of dystocia because of lack of weight and size (Makarechian et al, 1982; Wiltbank and Remmenga, 1982), weakness at the time of parturition, insufficient colostrum, weak calves at birth, and a high incidence of prolonged postpartum anestrus, which leads to a high percentage of nonpregnant animals that may have to be culled. If they are left in the breeding pasture to be bred over a period of 3 to 6 months, a high percentage ultimately conceives but they are late calvers in the next season. The high rate of culling of nonpregnant animals and late calvers among young beef heifers and cows is a major cause of economic loss in beef breeding herds. The effects of undernutrition on reproductive performance are greater in first- and second-calf heifers and cows than in older cows. Thus pregnant heifers should be fed and managed separately from cows and should be on a higher plane of nutrition than cows.

GENERAL HEALTH MANAGEMENT CONSIDERATIONS

Herd health is dependent on a number of factors that act to maintain collective immunocompetence. For many infectious diseases the greatest risk for initial introduction into a herd is with the purchase of subclinically infected animals that are carrying the infectious agent. The herd risk level for introduction of disease is thus related to the amount of contact that occurs with "outside" animals, with some risk also attributable to wildlife carriers. Potential sources of infection may occur with herd additions, or through advertent or inadvertent movements and contacts. Herds may be classified as "open," "closed," and "modified open," based on their potential for pathogen exposure (Spire, 1988). This classification may then be used to help plan the herd health program, as explained below.

Closed herds restrict the introduction of animals (probably only breeding bulls) as well as contact with other herds and animals, whereas modified open herds may replace animals from outside sources on a limited basis and allow other controlled contacts, such as at livestock exhibitions. In general, any incoming animals should be subject to the same herd health program as the regular herd. It is preferable to obtain these from herds whose herd health history is known and to have a record of vaccinations and treatments. It is also wise to quarantine newcomers while appropriate tests, observations, and vaccinations are performed. For pubertal bulls, such tests should include tests for campylobacteriosis and trichomonosis.

At the other end of the spectrum, open herds represent high risk for the introduction of pathogens. This risk occurs through such practices as regular introduction of purchased replacements (especially from commingled sale groups), direct introduction of stressed stocker calves (especially into high population densities), and mingling of animals of different backgrounds, through either cooperative breeding programs or poor herd biosecurity.

Situated between these two categories, modified open herds are characterized as those that limit the introduction of new animals and other animal movements and that have adequate herd biosecurity. In general, sound herd health management should include separating all purchased or introduced animals from the home herd for a reasonable observation period (e.g., 4 weeks) and for them to undergo the same health procedures as the home herd. If the origin of the newcomers is unknown, it is wise to test them for bovine leukosis, Johne's disease, and BVD (Stokka and Faulkner, 1998). Pubertal bulls should be tested for trichomonosis and vibriosis.

For AI programs, only semen should be used that was processed by an approved AI center with a comprehensive health program for minimizing the risk of transmission of venereal (and other) diseases through frozen semen. In North America, such assurance is obtained from AI collection centers that are affiliated with Certified Semen Services (CSS), the industry group that establishes guidelines for both bull health and semen quality control (see below).

Vaccinology

Although they form the basis of many herd health programs, vaccines vary widely in their efficacy. This variation occurs even when they are used properly (Gay, 1999). Improper use, including errors in storage, dosage, and site of administration, add to the probability of vaccine failure. Knowledge of factors such as appropriate vaccine choice, handling, and administration is more important than the actual vaccination schedule (Randle, 1993). In developing production

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medicine programs for cattle breeding herds, veterinarians need to advise on such aspects as replicating versus nonreplicating vaccines, number of doses required for effective protection, best timing of administration, storage and mixing of vaccines, location and route of administration (Randle, 1993), and withdrawal constraints. The effectiveness of any vaccine is dependent on a healthy immune system in the recipient. Overreliance on vaccinal protection can be mistaken if these considerations are not addressed.

Infertility Diseases

Although infertility is a major cause of loss to cow-calf producers, it is often insidious in nature and difficult to detect. True infertility is something that occurs before fertilization, such as when females are not cycling (or if cycling, not becoming pregnant). Although this definition differentiates infertility from disease entities that cause embryonic or fetal loss, this is often more difficult to do in practice. However, if this definition is accepted, then infertility in mature (postpuberal) female cattle is usually due to one or more of the factors listed in Box 13-16.

The presentation here does not describe each of these conditions in detail but briefly reviews the infectious causes of infertility from the diagnostic and managerial perspectives.

Trichomoniasis

Trichomoniasis is a contagious venereal disease (caused by *Tritrichomonas* [or *Trichomonas*] *foetus*) that is apparently widespread in beef herds (8% of bulls in Oklahoma and Florida, 15% in California herds), in which it is capable of causing significant economic loss through both delayed breeding and gestational loss (Rae, 1989).

In bulls *T. foetus* occurs on the penis and prepuce, localizing within epithelial crypts and smegma such that older bulls (4 years and older) tend to become chronic carriers. However, no clinical or pathological signs are reported in bulls. In females the organism colonizes the vagina, uterus, and oviduct. It produces vaginitis and endometritis with mild discharge. It does not interfere with fertilization but either directly or indirectly (through endometritis) starts to adversely affect the fetus from about 50 days' gestation, with death and subsequent resorption occurring around 100 days. Pyometra and abortion may occur, although they are rare. Infertility is a common sequel, probably resulting from initial fetal death and subsequent failure of conception or implantation. This infertility commonly lasts 2 to 5 months after which cows may regain fertility with some immunity. It is possible, however, for females to retain infection throughout pregnancy, although most will eliminate the organism at the first or second postpartum estrous cycle.

BOX 13-16

Causes of Infertility in Beef Herds

Nutritional problems (± suckling/lactation)
Bull infertility
Vibriosis (campylobacteriosis)
Trichomoniasis
Other infectious causes (e.g., *Ureaplasma*, infectious bovine rhinotracheitis, *Haemophilus somnus*)?

The most obvious sign in the herd is often females returning to estrus 3 to 4 months after they were bred. This may not be noticed with restricted breeding seasons such that first sign may be a lowered calf crop. Sometimes, the first indication may be an increased number of pyometras at pregnancy test. *T. foetus* can survive freezing and thus be transmitted with AI. It can also exist for varying periods on bedding. It is very contagious (80% to 90% of females bred to an infected bull will contract the disease). A tentative herd diagnosis for trichomoniasis may be obtained from analysis of herd pregnancy diagnosis records, which can provide important clues such as strung-out conception patterns or increased numbers of open females. Calving analyses can also provide similar information, only later. Increased pyometras and midterm abortions are also useful clues. However, the definitive diagnosis depends on identification of the causal organism. This is best done from the prepuce-penis of mature bulls (Rae et al, 1999), using a technique such as the "In-pouch," or Diamond's media, as the preferred culture media. Such preparations should be maintained at 37° C and examined microscopically at 24, 48, and 72 hours.

Risk factors for trichomoniasis in herds include commingling of cattle from different herds or backgrounds, failure to limit breeding season length, use of older bulls, failure to screen introduced bulls for trichomoniasis, poor fencing, and the continued presence in the herd of older or cull females (Gay et al, 1996). In bulls, carrier status appears to be related to the development of crypts within the penile and preputial epithelium. Such development is largely age related, although breed differences occur in the age at which some bulls may become carriers. For example, in the study by Rae et al (1999), several 2-year-old bulls were diagnosed as infected.

Losses resulting from *T. foetus* in cattle breeding herds may be substantial. In Oklahoma, annual calf loss in 1979 was estimated at $2.5 million (Wilson et al, 1979). A simulation model (Rae, 1989) estimated a reduction of 14% to 50% in annual calf crop when bull prevalence was between 20% and 40%, with net return per exposed cow being reduced by 5% to 35%. In large herds in which bull prevalence was up to 35.9%, cow performance measures were adversely affected by large numbers of infected bulls (Rae et al, 1999).

When trichomoniasis is diagnosed in a herd, a number of options exist. These range from doing nothing and living with the economic consequences, or the following:

1. AI with semen from an accredited AI center (AIC)
2. Vaccination (females only)
3. Culling of open cows and older bulls
4. Institution of "clean" versus "dirty" herds
5. Avoiding public grazing lands that are shared with other herds
6. Testing and removal of positive bulls and prevention of positive bulls from entering the herd

The last option, which depends on a reliable testing method and good animal identification and control, was used successfully in an extensive beef herd in Florida (Rae et al, 1999). Here, the mean prevalence of *T. foetus* infected bulls was 11.9%. Test sensitivity of the in-pouch diagnostic system was estimated for consecutive tests as follows: 73%, 90%, 96%, and 99%. Although this was lower than other published estimates for this technique (Skirrow et al, 1985; Kimsey et al, 1980; Gay et al, 1996), it is similar to AI industry estimates of average diagnostic sensitivity for trichomonosis (Monke, 1998). Reasons for lowered test sensitivity for trichomonosis are many. False positives are considered rare when experienced laboratory personnel are involved (with the possible exception of confusion with *Trichomonas enteris*, as below); false negatives are a possibility that can

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occur despite the effectiveness of the culture medium itself. Some possible reasons for this follow.

Restraint and Sampling. A preputial smegma sample should be obtained from the region of the glans penis and the adjacent preputial membrane. This should be as free from contamination as possible. These conditions are not always easy to fulfill, especially when fractious bulls are examined in poor facilities. Bulls that have recently completed natural or artificial vagina (AV) service may have a reduced population of *T. foetus* and a minimum 4-day interval without sexual activity before sampling has been advised. In bulls with large sheaths, standard insemination pipettes may not be sufficiently long to reach the preferred sampling site.

Transport and Culturing. The temperature of the transport-culture media should be as close to ideal culture temperature (37° C) as possible. Where this cannot be ensured, samples should be transported to a laboratory incubator as rapidly as possible. Temperature extremes, contact with atmospheric oxygen, and contamination should be minimized.

Interpretation. Technicians need to be trained to identify the telltale movements of *T. foetus* (best seen at a magnification of 100×) and to be diligent in searching for them. Cultures should be monitored regularly to detect overgrowth that can cause death of *T. foetus*, leading to a false-negative result. On occasion, confusion may be caused by the presence of an enteric trichomonad (*T. enteris*), which can resemble *T. foetus*. Here, definitive diagnosis is dependent on use of electron microscopy, or specific staining, to define fine structures.

Vaccination of cows and heifers against *T. foetus* is an option when disease is detected, suspected, or threatened (Kvasnicka et al, 1999). In the United States, this is achieved with a killed *T. foetus* product that significantly reduces abortion losses in challenged females and limits the duration of infection, although it does not prevent infection (Kvasnicka et al, 1999). The vaccine requires two administrations, 3 weeks apart and about 1 month before breeding, with an annual booster. Timing of the vaccination is important, with reports of diminishing effectiveness with increasing interval between vaccination and breeding.

Vibriosis (Campylobacteriosis)

Bovine vibriosis is a true venereal disease that is common in beef herds worldwide, where it is mostly associated with infertility. The causative agent, *Campylobacter fetus* var. *venerealis*, survives on the penis and prepuce of the bull, specifically within mucosal crypts, and within the female reproductive tract. It can also survive freezing so that it can be transmitted in frozen semen. Antibiotics are added to extenders to avoid this. It may also be transmitted from animal to animal through unsanitary AI practices.

In females, infected bulls deposit *C. fetus* in the vagina. After 1 to 2 weeks, organisms are throughout the uterus and can reach the oviduct (25%) within the same period. A progressive endometritis ensues, which reaches its peak at about 8 to 13 weeks after infection. Initially, fertilization may occur, but the embryo will either not survive for long, leading to a prolonged return to estrus, or later abortion can occur. If initial fertilization did not occur, a temporary failure of fertilization may occur due to failure of gamete transport. Normal cyclicity may be evident except at the first cycle, which can be prolonged. Abortions occur in a minority of infected females (3% to 5%), usually after 5 months gestation but sometimes earlier (2 to 3 months). Immunity usually develops after 4 to 6 months following initial infection. The duration of this immunity varies but it usually is minimal after approximately 4 years. Some females remain carriers.

In bulls, *C. fetus* localizes in the epithelial crypts of the penis and prepuce. Carrier status thus depends on the development of these crypts, usually in mature bulls (4 years or more). Younger bulls tend to have transitory infections. Mechanical transmission is very rare. However, bulls may become infected by contact with infected material. No clinical or pathological evidence of infection occurs in bulls.

In herds the most common sign of the disease is extra breeding activity and a "strung-out" calf crop resulting from the variable recovery periods of individuals and their initial susceptibility. Thus either heifers or first-calf females may show the worst effects—whichever group is first exposed to infected bulls. Bulls may become fatigued because of increased workloads.

A tentative diagnosis of the disease can often be made with the use of good herd records in conjunction with an understanding of disease patterns (although it may be difficult to differentiate between vibriosis and trichomoniasis). Valuable circumstantial evidence for the presence of either vibriosis or trichomoniasis in the herd can be gleaned from analyses of herd pregnancy diagnosis records. Samples may be taken from the vagina or cervix of selected females and cultured in special media. *C. fetus* is difficult to culture. Thus, at least 10 to 20 open, cycling females should be selected—excluding vaccinates and those that have aborted. Identification of *C. fetus* in one or more females is proof of herd infection. Laboratory methods of diagnosis are covered elsewhere. A sample may be taken from the bull's prepuce using a pipette or scraping device, with this being placed in a transport medium. However, bulls are generally not good candidates for isolation of *C. fetus*. The "gold standard" is to test breed a group of heifers with a suspect bull and then sample cervical mucus just before first estrus. Serology has been used as a herd-screening test, although this has severe problems and must be interpreted in light of vaccinations and other records. The mucus agglutination test is regarded as being more useful for herd screening.

Treatment options for females have been inadequately studied because of spontaneous recovery within 6 months. In bulls, carriers can be treated with antibiotics (e.g., local treatment with neomycin-erythromycin). Vaccination, using high antigen mass, has also been reported to clear bull infections.

Bacterins are commonly used for control, in either an oil (longer duration, bigger lumps) or aluminum hydroxide (shorter duration, smaller lumps) adjuvant. *C. fetus* vaccines are often combined with *Leptospira* (5 way) and, sometimes, with *T. fetus*. Effective protection is relatively short (4 to 8 months). Best protection is when vaccination is completed around 2 to 4 weeks before breeding. All breeding bulls and females should be vaccinated annually.

Management procedures may also be used to control or prevent vibriosis. Here, use of AI with semen from an accredited AI center is a safe option. Another option is to breed virgin bulls with virgin heifers to build up a "clean" herd. The judicious culling of open and late-pregnant females, as well as the use of young bulls, can reduce the deleterious effects of vibriosis to low levels. Vaccination of bulls alone is used by many producers, and this can be effective when herd biosecurity is ensured.

Ureaplasmosis

Ureaplasmas are common inhabitants of the respiratory and reproductive tracts of cattle, and they have been implicated in a number of reproductive syndromes (Sanderson and Chenoweth, 1999). They are assumed to cause considerable

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loss under certain conditions, which have yet to be specified. The causative agent, *Ureaplasma diversum*, has been implicated in a variety of reproductive tract disorders, including granular venereal disease, early embryonic loss, weak calf syndrome, abortion, and seminal vesiculitis in bulls. After experimental inoculation, granular vulvovaginitis occurred in 3 to 6 days followed by endometritis and salpingitis. Female susceptibility to *U. diversum* seems to vary, with heifers appearing to be particularly susceptible. CTC has been used in feed, with mixed results, to prevent or reduce the adverse effects of *U. diversum*.

Health Standards for Artificial Insemination Centers

A number of diseases have been shown to be transmittable in frozen semen. For this reason, the biosecurity and health programs of AICs are relevant to this discussion of cow-calf health. In the United States, most AICs are affiliated with the National Association of Animal Breeders (NAAB), and with its subsidiary, Certified Semen Services (CSS). CSS establishes rules and procedures for the certification of businesses that process livestock semen. These include requirements for testing both bulls and mount animals before entering isolation, during isolation, and while in residence at the bull stud. They also include general sanitary procedures and requirements for the addition of appropriate antibiotics to semen and extender to control specific microorganisms, particularly mycoplasmas, ureaplasmas, *H. somnus* and *C. fetus* subsp. *venerealis*. At present, the recommended antibiotics for this purpose are gentamycin, tylosin, and Linco-Spectin. Comprehensive standards are provided for those diseases known or suspected to be sexually transmissable. The underlying goal is to protect the herd into which the semen is being introduced. Thus use of semen from CSS-approved AICs is recommended, at least in the United States. Such semen is certified as CSS "Health Certified Semen" and will have the CSS logo imprinted on semen packages. Further information on CSS procedures and recommendations may be found at http://www.naab-css.org.

BULL SELECTION, ASSESSMENT, AND MANAGEMENT

Beef cattle numbers in the United States have remained relatively stable over the past quarter century, with the predominant breeding system being natural breeding at range or pasture. Since reproductive performance is the most important single economic trait in the cow herd, the reproductive capabilities of breeding bulls assume great importance. The best single assurance that a bull is likely to be fertile is for him to pass a breeding soundness evaluation (BSE).

In 1997 approximately 55% of U.S. beef *operations* had bulls semen tested before purchase, lease, or loan, with SC measurement being performed on 44%, up from 31% in 1993 (NAHMS, 1998b). Previously, 57.2% of respondents indicated that bull SC was either extremely or very important in bull selection, with 19.2% regarding it as not important at all (NAHMS, 1994a). In this survey, the three major bull selection criteria were breed, temperament, and structure-appearance. Paradoxically, infertility and physical unsoundness were the most important culling criteria for bulls.

The numbers of *operations* using bull assessment *before sale*, although not particularly high, contrasted with those that assessed bulls *before breeding*. Here, not only are estimates disappointingly low, but surveys indicate an overall decrease between 1993 and 1997 in both semen testing (18.3% and 17.0%, respectively), and SC measurement (10.8% and 8.9%, respectively). For actual *bull numbers* (in contrast to operations), the percentage of bulls subjected to a prebreeding semen test in 1997 was 30.1%, with SC being measured on 17.7%. Together, these data indicate several trends. One is for bulls to be assessed at only one time in their breeding careers (e.g., before sale, lease, or loan). In general, larger operations more commonly use bull reproductive exams than do smaller ones (NAHMS, 1998a). Despite this, bull management was identified as a prime area for increased veterinary involvement in major cow-calf regions of the United States where cow herd sizes were larger than average (Sanderson and Gay, 1996). An apparent decrease in use of a prebreeding bull BSE by industry between 1993 and 1997 (NAHMS, 1998b) may reflect a trend to reduce veterinary inputs at times of low calf prices.

Relationships Between Bull Breeding Soundness Evaluation and Fertility

There is a considerable amount of supportive evidence that links the BSE and/or its components with bull fertility. An earlier study (Cupps et al, 1959) concluded that impaired breeding efficiency occurred when sperm motility was below 37% and normal sperm morphology below 65%. In Nebraska, a natural breeding study found that bulls classified as satisfactory, questionable, and unsatisfactory obtained average pregnancy rates of 75%, 52%, and 12%, respectively, although individual bulls varied within categories (Wiltbank et al, 1965). The conclusion was that the average fertility of categorized bulls could be predicted with some reliability, although individual bull fertility prediction was less reliable. The most predictive aspect of semen quality was percent abnormal sperm followed by sperm motility. In Texas trials, cows were mated with bulls having 80% or greater normal sperm, or with unselected bulls. Subsequent pregnancy rates were 93% and 87%, respectively (Wiltbank and Parish, 1986). In a second trial, heifers were bred to bulls of three sperm morphology categories; 80% plus normal sperm, 70% plus normal sperm, and unselected controls. The respective pregnancy rates were 90%, 91%, and 85%. The conclusions were that bulls preselected for good sperm morphology (70% or 80% normal) could achieve 5% to 6% more pregnancies than unselected bulls, and that 70% normal sperm was a reasonable threshold.

In an attempt to increase breeding pressure on bulls, and thus accentuate differences in male fertility traits, several trials used bulls with groups of heifers that had been treated to synchronize estrus. In one such series (Mateos et al, 1978), "satisfactory" BSE bulls obtained a pregnancy rate advantage of 10.5% over those categorized as questionable (actual pregnancy rates of 53.6% and 43.1%, respectively). Here, each of three major components of the BSE (SC, sperm motility, and percent normal sperm) were associated with pregnancy rate (all $p < .05\%$). In a similar study, satisfactory bulls obtained a pregnancy rate advantage of 6% to 9% compared with questionable bulls (Farin et al, 1989). Another approach has used blood-typing technology to determine calf parentage, and thus the fertility of bulls in multi-sire breeding herds. In one study the most important bull factors were found to be large SC, low numbers of primary sperm defects, and lesser amounts of backfat (Coulter and Kozub, 1989). Also in Canada, prior BSE screening of bulls in a large herd caused increased pregnancies (3.5%) in a shorter breeding season while using less bulls (BFR went from 1:20 to 1:30) and increased calf weaning weights (Prince et al, 1987). This last observation indicates that females became pregnant earlier in the breeding season, causing older, and heavier, calves at weaning.

Studies in tropical and subtropical regions have shown encouraging results for the BSE and/or its components. In a

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study in Northern Australia (Bamualim et al, 1984), BSE score had some ability to predict a bull's fertility over the subsequent breeding season ($p < .01$) and also over the bull's lifetime ($p < .05$). Here, semen quality was positively associated with pregnancy rate. In a similar environment, a study in which bulls were examined at various intervals from 11 months before mating found the most important factors in bull fertility "indexes" to be testicular volume, sex drive, induced luteinizing hormone (LH) levels, and body weight (Perry et al, 1990). Age and dominance value (a measure of social dominance) also played a role in the derived indices that were highly related to pregnancy rate. A study with Brahman bulls in a more extensive beef region of Northern Australia (McCosker at el, 1989) exploited calf blood-typing to determine major influences on bull fertility in multisire herds that had BFRs of 1:20 to 1:33 and a breeding season of 124 to 190 days. Here, low and variable bull fertility was associated with bulls that had low BSE scores. Bull SC and BSE score influenced bull fertility (both $p < .05$), as did dominance value. The use of only sound bulls caused substantially higher pregnancy rates at lower BFRs (1:33 versus 1:20). Most recently, a large-scale study (12 sites, 245 bulls) in North Queensland used DNA parentage technology to determine the major effects influencing fertility in *Bos indicus* derived bulls (Fitzpatrick et al, 1998). Here, highest calf crops were obtained from bulls with more than 70% normal sperm, whereas bulls with less than 50% normal sperm sired relatively few calves. The conclusion was that "semen quality, particularly percent normal spermatozoa, was consistently related to calf output." Important relationships at different sites were obtained between bull fertility and percent normal sperm, dominance, sex drive, SC, and sperm motility. The summation was that "these results confirm that semen examination, including sperm morphology, should be standard procedure when assessing bulls for reproductive soundness."

In the United States, bull influences on conception rates were studied over a number of years in both *Bos taurus* and *Bos indicus* cattle at USDA-STARS, Florida (Larsen et al, 1990). Significant effects on conception rate were associated, positively or negatively as expected, with the prevalence of normal sperm ($p < .01$), proximal droplets ($p < .01$), and percent "primary" abnormals ($p < .01$). Here, bull age, sex drive, and length of breeding season also influenced fertility parameters.

From the studies just mentioned, which embrace a variety of regions, genotypes, and managerial conditions, the resounding conclusion must be that the bull BSE, an otherwise quick and inexpensive screening procedure, is a highly effective tool in reducing the uncertainty associated with bull purchase and usage. Thus a "rough" estimate may be made of a 6% or greater fertility advantage for bulls passing a BSE or semen quality thresholds over unselected bulls, with larger differences possible when satisfactory bulls are compared with those that fail the BSE. Additional benefits accrue through increased weaning weights of older calves at weaning.

Bull-to-Female Ratios

Studies indicate that traditional recommendations of BFRs between 1:25 and 1:30 for herd bulls often lead to underuse of competent bulls. For example, one study comparing single and multiple sire of Hereford bulls in natural breeding herds at BFRs of 1:25, 1:44, and 1:60 concluded that "the fertility, libido and mating ability of each sire was more important than the BFR or the matter of single- vs multiple-sire breeding systems" (Rupp et al, 1977). Similarly, in Northern Australia, there was no difference in reproductive rates between single- and multi-sire herds studied over a period of 18 years (Bamualim et al, 1984). In Colorado, yearling Hereford bulls were compared at BFRs of 1:20 (single sire) and 2:40 (multisire) with synchronized crossbred heifers (Farin et al, 1982). Here, with the exception of number of services per heifer, bull-mating performance and pregnancy rates did not differ between BFRs of 1:20 and 2:40. Since considerable bull overlap occurred in multi-sire groups, it was concluded that single-sire mating was inherently more efficient. Comparison of a variety of single-sire BFRs (1:7 to 1:51), also with females subjected to synchronization treatment, found that BFR was not a limiting factor to fertility, even at higher levels of breeding stress (Pexton et al, 1990). Rather, bull age and fertility appeared to be most important. In these trials bull service activity increased with stimulus pressure, such that upper recommended limits for BFRs "may not be justified." In Northern Australia, no difference was observed in herd fertility when reproductively sound Brahman bulls were used at BFRs of either 1:17 or 1:40 (Fordyce et al, 1998). As previously noted, two studies in vastly different environments showed that use of bulls that had been prescreened with a BSE increased both BFRs (1:20 to 1:33) and herd pregnancy rates (Prince et al, 1987; McCosker et al, 1989).

Thus it is apparent that sound bulls that have passed the BSE can handle considerably more females in a generic breeding season than would be suggested by traditional recommendations. It is also evident that most producers have yet to take full advantage of these findings. For example, surveys indicate that cow-calf operations overall use yearling bulls at 1:17.5 and mature bulls at 1:25 (NAHMS, 1998b). A survey of cow-calf producers in the Rocky Mountain West revealed a mean BFR of 1:21, with 25% of herds using a BFR of less than 1:18 (Sanderson and Gay, 1996).

Bulls are a major cost item for most cattle breeding operations. Exploitation of the BSE can reduce bull numbers while enhancing fertility rates. It would be difficult to find a better example of a procedure guaranteed to improve the "bottom line" for cow-calf producers.

Genetic Considerations

Although the heritability of reproduction in cattle is generally regarded as low, a number of traits associated with bull fertility are relatively highly heritable. SC in bulls is a major example, with this trait being moderately to highly heritable in beef bulls (approximately 50%) and is favorably related to seminal traits. In general, as SC increases in young bulls, so do sperm numbers and aspects of semen quality (Coulter, 1994). Genetic correlations between SC measures and growth traits are generally favorable for young beef bulls (Coulter and Kastelic, 1999), although some variations occur. Lack of a significant relationship between birth weight and SC suggests that selection for SC can be achieved without increasing dystocia rates. There are suggestions that selecting bulls for larger SC will enhance growth characteristics, as well as their maternal value (Coulter and Kastelic, 1999). Importantly, studies indicate strong links between SC in young bulls and age at puberty in related females, and favorable relationships have also been reported with other female reproductive traits in cattle (Coulter and Kastelic, 1999). Heterosis also benefits both bull SC and heifer age at puberty (Gregory et al, 1991). Selection using SC EPDs was shown to be more effective than phenotypic selection in reducing age at puberty in daughters (Moser et al, 1996). Bull SC is an accurate predictor of bull puberty (Lunstra, 1982), with remarkable agreement between breeds in pubertal SC. With females, earlier age at puberty has been associated with improved lifetime fertility and pounds of calf produced (Brinks, 1994).

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One possible caveat occurs with selection for SC, with particular reference to selection for extreme growth. Here, anecdotal evidence suggests that spermatogenesis may be affected adversely in young bulls with extremely large testicles. Further work is needed to clarify this observation. Testicular tone, as measured with a tonometer, has also been shown to be moderately heritable and associated with semen quality (Coulter et al, 1976).

A number of positive genetic relationships occur with BSE traits in beef cattle. Thus use of BSE criteria to select bulls for scrotal circumference (and associated improved semen traits) can help to improve immediate and future herd fertility and production through a number of mechanisms.

Bull Fertility Assessment

Bull fertility is influenced by a number of traits, including semen quantity and quality, libido and mating ability, and social interactions (dominance effects) within the breeding pasture (Chenoweth, 1994b). In addition, bull performance is limited by the fertility threshold of the female herd (Saacke et al, 1991), and it can be complicated by the size and terrain of the breeding pasture as well as by the presence of infertility disease.

Thus herd fertility is influenced by a number of factors that may, or may not, act in tandem. This consideration helps explain why avid pursuit of single trait relationships with fertility is often destined to give disappointing results. Despite this, both reason and scientific evidence support the pivotal role of bulls in herd fertility. Bulls differ markedly in their reproductive capacities. Conservative estimates indicate that at least 20% of unselected bulls are relatively infertile. Procedures used to evaluate bulls have been shown to be effective in identifying many of these infertile bulls. For these reasons, bull evaluation represents an important "marketable skill" for veterinarians. The procedures involved in such evaluations are remarkably consistent throughout the world. In North America these have been formalized by the Society for Theriogenology into a standardized form that has been modified over time as knowledge has accrued (Chenoweth et al, 1992). This procedure (Chenoweth et al, 1993) is described in detail below. Standards for bull evaluation have also been published separately by the AACV (Anon, 1995), as well as the Western Canadian Association of Bovine Practitioners (Barth, 1993).

Bull Breeding Soundness Evaluation

The BSE represents a relatively quick and economic procedure for screening bulls before sale or use. It aims to place bulls into different categories, which generally perform as predicted. It is most effective in identifying bulls at the lower end of the potential fertility spectrum. However, this in itself represents good infertility "insurance" and can be useful in helping to improve "genetic" fertility of the herd. The BSE, however, is relatively less effective in its ability to accurately predict individual bull fertility at the upper end of the spectrum. Reasons for this include the following:

1. Fertility is a complex trait that is influenced by both male and female traits as well as by extraneous factors.
2. The BSE is a relatively quick and simple screening procedure that does not attempt to comprehensively assess all aspects of male fertility.
3. The BSE aims to identify bulls that are satisfactory (not necessarily those that are superior).
4. Knowledge and understanding of male fertility keep increasing and changing.

This last factor, in particular, provided the impetus for the American Society for Theriogenology to revise their recommended bull BSE procedures, which had been in effect since 1975. This new system (Chenoweth et al, 1993), in concert with general principles of bull evaluation, is described below. Forms and background information for this procedure may be obtained by members of the American Society for Theriogenology at 530 Church St., Suite 700, Nashville, TN 37219.

Timing of the BSE. Veterinarians should conduct a BSE on all pubertal bulls before sale or purchase. In addition, since many problems can occur over a 12-month period, it is recommended that bulls undergo a BSE every year, preferably before breeding. The optimum time to perform this procedure in relation to start of breeding usually involves a compromise. Predictability of the test increases when it is performed close to the start of breeding. However, it is often necessary to provide enough latitude in timing to allow for retesting (and perhaps treatment) and for identification and screening of replacements. Because of these considerations the BSE is often conducted within 2 to 4 weeks of the start of breeding.

General BSE Procedures. The primary mission of the natural breeding bull is to efficiently impregnate all available females as early in the breeding period as possible. To achieve this he must possess the physical and reproductive necessities to perform this task. These include good eyesight and musculoskeletal conformation as well as the necessary reproductive equipment and sex drive to produce and appropriately deliver sufficient numbers of fertile spermatozoa. To adequately assess all of these aspects within a short period is a tall order. The routine BSE attempts to achieve this through the following steps:

1. Physical examination
2. Reproductive examination (including measurement of scrotal circumference)
3. Collection and examination of semen

In addition, a libido-mating ability test may be included, as may special tests for diseases (e.g., vibriosis or trichomonosis). These procedures will add predictive value to the assessment process and may be indicated specifically in some situations, but they are not part of the routine BSE.

It is very important to inform clients not only of the advantages of the BSE but also of its limitations. With the latter, it is sobering to consider the inherent difficulties of trying to predict future performance based on historical events. With semen characteristics it may take weeks or even months before the effects of spermatogenic insult may be fully reflected in the ejaculate. Limitations of the BSE include the following:

- Results are most valid at the time of examination only
- The system works best to identify infertile bulls
- It is not designed to predict the precise fertility of individual bulls
- Unless specifically included, there is no assessment of bull libido and mating ability
- Unless specifically included, there is no testing for infertility diseases

Restraint Considerations. A safe, secure bull restraint system is most important for this task. The examiner should have safe access to both the rear end of the bull and his underbelly without undue fear of injury. The bull should also be unable to injure himself. Head catches should ensure that bulls do not injure, or even kill, themselves if they collapse in the chute or crush. Some bulls (e.g., many *Bos indicus* types) are more tractable if their head is not restrained during the BSE. Squeeze chutes, especially hydraulic ones, are effective in constraining excessive bull movements. If a bar or chain is placed behind the bull to prevent rearward movement, then palpation of the testicles should always be conducted below this device. Secure footing should be provided

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for the bull in the chute. Here, a backstop for the hind feet can be useful for bulls undergoing electroejaculation (EEJ).

Identification and Ownership of Bulls. It is important to establish permanent and unique identification of each bull as well as the establishment of ownership. It is a sound practice to also identify all samples, slides, and worksheets with the bull identification number.

Body Condition and Other Body Measures. The body condition (or degree of fatness) of bulls is relevant to their reproductive assessment. Excessively fat or thin bulls may have problems with semen quality, libido, or mating ability as well as bull fertility in general (Coulter and Kozub, 1989). Poor body condition may also reflect health problems apart from poor nutrition.

Bull pelvic size in bulls is related to pelvic size in their daughters, which may be an important consideration in dystocia management. This information may be recorded.

Structure, Conformation, and Movement. Ideally, the bull should be allowed to move freely so the veterinarian can observe gait and movement. Once in the chute or crush, the veterinarian should pay close attention to limbs, joints, and claws. The bull should have good, symmetrical musculoskeletal formation, and he should walk with a smooth action. Asymmetrical or overgrown claws and swellings over lower limb joints are common abnormalities and may reflect poor conformation, pathological conditions, or both. Conditions such as chronic lameness, sole abscesses, arthritis, severe quarter cracks, interdigital fibromas, and footrot can adversely affect mobility, mating ability, and libido as well as contribute to testicular degeneration if the bull is semirecumbent. High body temperatures associated with footrot, or pyrexia from any other cause, can also cause spermatogenic dysfunction. Since the hind limbs are most important in supporting bulls during service, hind limb and joint structure should be examined most critically. Poor conformation (e.g., "post legs," "cow hocks") is highly heritable in bulls (McNitt, 1965) and contributes to bull breakdowns in the breeding pasture. Back problems, particularly spondylosis-spondyloarthrosis of the lumbosacral joint, are not uncommon in bulls, even those relatively young, and contribute to service disabilities and loss of libido.

Physical and Reproductive Examination

For a bull to be a functional breeder, he must be able to eat, see, and move about without discomfort. Thus a thorough physical examination is indicated. A systematic approach should be used that emphasizes those aspects most important for breeding success.

Once in the chute or crush, the bull's eyes should be examined for any indication of impaired vision. This is particularly important because bulls use vision as their primary sense in detecting estrus females. Examination of the bull's teeth allows verification of age and helps to ensure that dentition is adequate for foraging.

The sheath of the bull should be inspected and palpated. The penis is palpable within the sheath, although it is often most convenient to examine it when extended during EEJ. On palpation, it should be symmetrical, freely moveable, and have no associated abnormal masses.

Scrotal conformation should be evaluated, since this can influence testicular development and function (Coulter, 1994). Optimum spermatogenesis occurs at 4° to 5° C below internal body temperature. This temperature gradient is maintained through a complex system that entails mechanisms to raise and lower the scrotum and testicle and to transfer heat from the pampiniform plexus to the external environment through the scrotal neck. Any factor that interferes with any of these mechanisms can lead to defective scrotal thermoregulation, with resultant deleterious effects on semen quality and sperm production. Studies using thermography indicate that abnormal scrotal temperature gradients in bulls can provide indirect evidence of potential fertility problems (Lunstra and Coulter, 1993). Optimum thermoregulation of the testicle occurs when the scrotum hangs vertically, and the scrotal neck is distinct (Coulter, 1994).

Although some variation in size between the two testicles in the bull is common, significant differences in the size and shape of either testicle should be cause for further evaluation. A disparity of more than 25% in the size of either testicle should be regarded with suspicion. The most common cause of marked scrotal asymmetry is unilateral testicular hypoplasia—a condition that might be presented as a putative "undescended" testicle. It is relevant to note here that definitive diagnosis of testicular hypoplasia necessitates use of testicular histological methods. Practitioners should be cautious when using this term without such evidence. A variety of congenital, traumatic, or infectious conditions may also lead to reduced testicular size, with testicular degeneration and aplasia being most common.

Testicles should be palpated for hardness and resiliency; a normal testicle should be firm and resilient (similar to a new tennis ball). A tonometer developed for bull testicles has been used with a spectrum of results. "Soft" testicles often reflect testicular degeneration and are found more often in older bulls and in bulls that have undergone thermal stress. This latter often includes bulls that spend a lot of time lying down. "Hard" testicles usually reflect fibrosis, which is often a result of testicular degeneration, but they may also occur with acute orchitis in which increased heat and other signs of inflammation can usually be detected. Recent developments in both diagnostic ultrasound and thermography hold promise for improved diagnostic capabilities in relation to dysfunctions of scrotal contents and the testicular parenchyma.

The epididymides (head, body, and tail) should be palpated. Problems detectable here can include inflammation, fibrosis, abscessation, hypoplasia, or aplasia.

To complete the examination of the external genitalia, the penis of the bull should be exteriorized, with this examination often performed during EEJ.

A per-rectal examination of the bull is an essential step to enable evaluation of internal reproductive structures. This examination normally includes identification and palpation of (in order) the pelvic urethra, prostate gland, vesicular glands, ampullae, vasa deferentia, and internal inguinal rings. The most common abnormality encountered is often that of accessory genital disease, which is most readily recognized as seminal vesiculitis. Segmental aplasia-hypoplasia of the embryonic Wolffian duct system may also be detected, although this is relatively rare.

Scrotal Circumference. SC measurement is an important part of the bull BSE, because testicular size in bulls is positively associated with sperm production and semen quality as well as with the age at puberty of related females (Brinks et al, 1978). Genetic correlation estimates have been obtained between SC in yearling bulls and age of puberty in half-sib heifers of −0.71 and −1.07 (Brinks et al, 1978; King et al, 1983). In turn, age at puberty in heifers is favorably associated with lifetime reproduction and production traits (Brinks, 1994). Adjustments for SC based on dam age and that range from 0.025 to 0.032 cm/day have been suggested for use of SC as a selection criterion with yearling beef bulls (Brinks, 1994), with the adjustment factors shown in Table 13-30.

The measurement of SC is simple and repeatable and does not require expensive or highly technical equipment to

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TABLE 13-30

Age of Dam Adjustment Factors for Yearling Beef Bulls

Age of Dam (yr)	Adjustment Factor (cm)
≥5	+0.0
4	+0.4
3	+0.8
2	+1.3

Adapted from Lunstra DD, Gregory KE, Cundiff LV: *Theriogenology* 30:127, 1988.

TABLE 13-31

Adjustment Factors for Bull Scrotal Circumference Measures Taken at Weaning

Breed	Age Adjusted (cm/day)	"B"
Angus	0.856	1.54
Brangus	0.861	1.60
Charolais	0.077	1.54
Hereford	0.042	1.41
Simmental	0.085	1.59

Geske GM, Schalles RR, Zollner KO: Yearling scrotal circumference prediction equation and age adjustment factors for various breeds of beef bulls. Proceedings of the Cattleman's Day Report, Kansas City, 1995, Kansas State University.

perform. The approved technique is to snugly apply a tape around the greatest circumference of both testicles, which should be manipulated to ensure that they are as close to the bottom of the scrotum as possible. A reliable procedure is to take two measurements to ensure accuracy, with two consecutive measurements not varying by more than 1.0 cm. Although this technique is easily learned, variations in results between evaluators led to development of a spring-loaded tape that was precalibrated to provide standardized results (Coulter and Kastelic, 1999).

Several studies have examined the relationships between prepuberal and subsequent SC (Pratt et al, 1991; Geske et al, 1995). The possibility of being able to use SC as a selection or screening criterion in prepubertal bulls poses considerable economic advantage. Both studies confirmed that bulls with small prepuberal testes were unlikely to develop large testes after puberty. In the latter study, SC was measured on 329 bulls, representing different beef breeds, at the start of a 140-day gain test and at 365 days of age. Threshold SC at start of the gain test, to achieve 30 cm by 365 days of age,

TABLE 13-32

Minimum Thresholds for Bull Scrotal Circumference

Age of Bull (mo)	Minimum SC (cm)
≤15	30
>15 ≤18	31
>18 ≤21	32
>21 ≤24	33
≥24	34

Chenoweth PJ, Hopkins FM, Spitzer JC, Larsen RE: Guidelines for using the bull breeding soundness evaluation form, Theriogenology Handbook Fact Sheet, B-10 (7/93), 1993, Society for Theriogenology, American College of Theriogenologists.

was 23 cm for Angus, Simmental and Zebu-derived breeds and 26 cm for other continental breeds and Polled Shorthorn bulls. In Kansas, Geske et al (1995) determined that a scrotal circumference of approximately 21 cm was necessary at 205 days of age for British and European-breed bulls to achieve 32 cm at 1 year of age, with adjustment factors being calculated for the different breeds studied (Table 13-31). Scrotal circumference thresholds recommended by the Society for Theriogenology for a "satisfactory" breeding bull are shown in Table 13-32.

The thresholds just described represent minimum standards designed to have wide application as well as acceptability for bulls of diverse genotypes and raised in a variety of environments to be classified as "satisfactory prospective breeders." On a regional basis, veterinarians are urged to work with breed associations, breeders, and sales organizations to elevate these standards where data are supportive. Here, data can be used to fine-tune the system to reflect different biological types of cattle; they can also be used where nutrition is consistent. For example, minimum standards have been established for different genotypes raised under similar conditions (grain fed in pens) in Western Canada (Table 13-33). Also, higher standards may be used where the objective of the evaluation is to identify "superior," rather than "satisfactory," prospective breeders.

Semen Collection

Semen can be collected from bulls by a variety of means including per-rectal massage, use of an AV and EEJ. The latter method is the one most commonly used with range-type bulls, and it is highly efficient in obtaining a representative semen sample from pubertal bulls. Such samples are comparable with those obtained with an AV in terms of semen fertility and freezability (Singleton, 1970). Modern machines and probes cause much less physical reaction in bulls than did earlier machines (Ball, 1986). Welfare aspects of this procedure are addressed later in this chapter.

Electroejaculators and Probes. Commercially available electroejaculators are available with power provided by AC current, by internal rechargeable batteries, or by 12-volt automobile batteries. Effective EEJ necessitates the stimulation of pelvic nerves controlling not only the emission of semen into the penile urethra but also those controlling erection

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TABLE 13-33

Recommended Minimum Scrotal Circumferences (in centimeters) for Grain-Fed Bulls in Western Canada

Age of Bull (mo)	Simmental	Angus, Charolais, Maine Anjou, Gelbvieh	Hereford, Shorthorn, Galloway	Limousin, Salers, Blonde d'Aquitaine	Texas Longhorn
12	32	31	30	29	28
13	33	32	31	30	29
14	34	33	32	31	30
15-20	35	34	33	32	31
21-30	36	35	34	33	32
>30	37	36	35	34	33

Barth AD: Bull breeding soundness evaluation, Western Canadian Association of Bovine Practitioners, Saskatchewan, Canada, 1992, Western College of Veterinary Medicine, University of Saskatchewan.

and ejaculation. Newer probe designs have full-length longitudinal electrodes that stimulate all functions simultaneously and cause considerably less muscle contraction than earlier probe designs, such as those using bipolar ring electrodes (Ball, 1986). Available machines vary in control mechanisms and features, with several being capable of preprogrammed stimulation regimens. Variations on stimulus patterns occur with different machines and operators. However, an overriding consideration should always be the welfare of the animal. Stimulation should be discontinued if either undue stress is being caused or physical injury to the bull might occur.

Preparation and Stimulation. The bull's rectum should be emptied of feces before the probe is inserted. The lubricated probe is inserted so that the anal sphincter closes behind the main body of the unit. Procedures for EEJ of bulls are described elsewhere (Chenoweth et al, 1992). However, an important consideration is to ensure that a representative semen sample is collected. Failure to collect a representative ejaculate can lead to errors of interpretation of the spermiogram. This is because the initial portion of the ejaculate may contain large numbers of degenerating spermatozoa in bulls that have not been recently sexually active. Similarly, if an ejaculate shows substandard motility in the absence of an obvious physical cause, a second sample collected within a short period of time (e.g., 5 to 10 minutes) can often show improvement in this trait.

Another important consideration is that, unless the penis is exteriorized for examination, difficulty exists in ensuring that it is problem free. Penile conditions that may be observed at this time include adhesions, phimosis, paraphimosis, fibropapilloma, persistent frenulum, hair rings, and some circulatory disorders of the corpus cavernosum. The approach to be taken with penile frenulums is subject to debate. Many of these can be separated relatively easily while the bull is still under the influence of the electroejaculator, and this is the routine approach often taken. Despite this, there is evidence that the condition can be highly heritable (McNitt, 1965). Further complication arises from evidence that many bulls evidently undergo natural separation of weak attachments before the BSE. The best advice for purebred breeders should be to select against persistent penile frenulums where practicable. Another caveat occurs with deviations of the bull penis. Here, although deviations of the penis may occasionally be observed at the time of EEJ, definitive diagnosis should await their observation during actual breeding attempts. This is because the fibrous architecture of the bull penis is such that it has a natural tendency to spiral, and EEJ can override normal control mechanisms. In fact many bulls will "corkscrew" during the ejaculatory process (Seidel and Foote, 1969).

Collection Devices. Semen should be collected into a prewarmed insulated or jacketed tube. All surfaces coming into contact with semen should be clean, warm, dry, and free of spermatoxic agents. Because "cold shock" causes irreversible damage to spermatozoa, efforts to maintain semen at 30° to 35° C until the "on-site" evaluation procedures are complete are important considerations for successful semen assessment.

Semen Evaluation

Initial Impressions. Volume, density, and gross characteristics of the ejaculate are not "front-line" BSE assessments because they have not been shown to be directly related to fertility. However, the recording of such information might be useful under some circumstances. Likewise, the assessment of spermatozoal concentration is not a routine part of the BSE because the measurement of scrotal circumference provides a better estimate of sperm production in range-type bulls that are subject to infrequent examinations. However, informal recording of such information may help to monitor the success of semen collection and to interpret gross motility estimation.

Other gross characteristics that may be noted include evidence of contamination, hemorrhage, or inflammatory material. If the ejaculate contains sufficient purulent material for this to be obvious to the naked eye, then that bull should not be classified as satisfactory at least until a benign cause is found. Debris or contamination from the sheath may be regarded as being less serious unless it represents active infection.

Sperm Motility. Sperm motility should be assessed microscopically. Two methods of assessing sperm motility are traditionally used: gross motility (or mass activity) and individual motility (or percent progressive motility). It is worthwhile to use both methods because they can differ somewhat in interpretation and precision. With all motility

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estimations it is important to protect semen against adverse effects (e.g., cold shock) and to do the estimation as soon as possible after semen collection.

Gross motility, or the amount of swirling (or wave motion) present in an undiluted semen sample, is a function of both sperm concentration and individual motility. Under field conditions, gross motility is typically assessed by placing a drop of raw semen on a warmed slide and observing it at 100 magnification (103 eyepiece and 103 objective). With the condenser properly adjusted, mass action or "swirl" can be observed in samples that have a sufficient concentration of motile spermatozoa to produce this effect. The rankings for this estimate are shown in Table 13-34.

Individual progressive motility of spermatozoa is assessed under a brightfield or phase-contrast microscope, preferably equipped with a warm stage or other means of preventing cold shock of spermatozoa. Cover-slipped specimens are usually examined at a total magnification of 400×. In dense samples (milky or creamy) the sample should be diluted for proper observation of individual spermatozoa, as it is common for operators to make the error of overestimating sperm motility in dense samples. Sodium citrate- or skim milk-based semen extenders are serviceable diluents; physiological sterile saline (PSS) may be used, although readings should not be delayed when it is used. The percentage of active, progressively motile cells is estimated. This procedure takes more practice than does the gross motility estimation but is probably more accurate in experienced hands. Individual motility ratings are shown in Table 13-35.

Observation of the semen sample at 400× can also help to identify the presence of other cells (e.g., squamous epithelial, inflammatory, or spermatogenic cells) within the sample. When these occur in numbers such that more precise identification is needed, other staining procedures should be considered. The identification of aberrant cellular material can benefit from the staining of a semen smear with Dif-Quik, New Methylene Blue, or other differential blood cell stains, whereas bacteria may be categorized using a Gram stain.

TABLE 13-34

Rankings of Gross Motility

Mass activity (gross motility)	Rating
Rapid swirl	Very good
Slower swirl	Good
General oscillation	Fair
Sporadic oscillation	Poor

TABLE 13-35

Individual Motility Ratings

Progressive motility	Rating
≥70%	Very good
50% to 69%	Good
30% to 49%	Fair
<30%	Poor

Morphology. Morphology of spermatozoa (differential counts of normal and abnormal cells) is assessed either by phase-microscopy with "fixed" semen preparations (using formol-buffered-saline or PBS-glutaraldehyde, for example) or by using brightfield microscopy of stained smears. Common stains used for this purpose include nigrosin-eosin, William's stain, and modified Giemsa. The Society for Theriogenology recommends use of the nigrosin-eosin stain for its combination of ease and utility. Although this stain may also be used as a "supra-vital" stain (i.e., sperm that are "alive" at staining will not absorb stain, whereas those that are "dead" will partially or completely absorb the red eosin color), here it is primarily used for its ability to depict sperm morphology only.

Brightfield microscopy of stained smears is best done at 1000× plus using an oil immersion lens. At least 100 spermatozoa should be observed in different fields and classified for normality or abnormality. To achieve a "satisfactory" BSE category, bulls should have at least 70% normal sperm. This threshold applies regardless of the types of sperm abnormalities involved.

In some evaluation systems, sperm abnormalities are placed into different categories that reflect either their presumed origin or their significance regarding fertility. One widely used system classifies sperm abnormalities as being either "primary" or "secondary" (Blom, 1950), on the assumption that primary abnormals (considered to be caused during spermatogenesis) were more serious than secondary abnormalities (caused subsequent to sperm release into the extragonadal system). Even though this system presents problems in interpretation, it has been retained as the reference point in the present system. Although total abnormalities only are used as the threshold in the new BSE system, "primary" and "secondary" abnormalities can be collated to arrive at this number. The recording of such information can also be useful for decisions on prognoses, and for monitoring progress, in problem bulls (Box 13-17).

The final step of the BSE is to place bulls into one of three categories, as follows.

Satisfactory. These bulls equal or surpass the minimum thresholds for scrotal circumference, sperm motility, and sperm morphology and do not show genetic, infectious, or other problems or faults that could compromise breeding or fertility.

Unsatisfactory. These bulls are below one or more thresholds and are highly unlikely to ever improve their status. Also included are bulls that show genetic faults or irrevocable physical problems (including infectious disease) that would compromise breeding or fertility.

Classification Deferred. Any bulls that do not fit into the above categories and that could benefit from a retest should be scheduled for a retest. This category would include bulls with an "immature" semen profile* as well as any bulls whose semen is substandard but considered capable of improvement. Also in this category are bulls from whom a satisfactory ejaculate could not be obtained for reasons unknown as well as bulls with treatable problems such as seminal vesiculitis or footrot. In general, if any doubt exists about a bull fitting into either the satisfactory or unsatisfactory categories, he should be considered as a candidate for a retest and placed into the "classification deferred" category.

*It is not uncommon for yearling bulls to exhibit higher levels of certain types of spermatozoal abnormalities that are associated with immaturity. Such bulls will usually require a second examination before being classified as a satisfactory potential breeder.

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Behavioral Aspects of Bull Fertility

Bull Libido–Serving Capacity. The ability of a bull to produce good semen does not necessarily guarantee that he has the urge and ability to deliver this where and when necessary. Thus much work has been done to define the role of bull sex drive in relation to bull reproductive performance. Sexual behavior in the bull includes behavior associated with the detection and service of estrus females. Libido, or sex drive, is the "willingness and eagerness" of a bull to attempt mounting and service. Mating ability refers to the ability of the bull to complete service. Serving capacity is a measure of the number of services achieved by a bull under stipulated conditions and thus includes aspects of both libido and mating ability.

Assessment of Sex Drive in the Bull. Libido is a measurable behavioral trait (Box 13-18). Testing procedures that have been developed for bulls have generally exploited several or more of the following findings (Chenoweth, 1997):

1. Libido in bulls has a significant genetic component
2. Bulls are polygynous and tend to distribute their services among receptive females.
3. The greatest single stimulus for bulls to attempt mounting and service is an immobile object that resembles the rear end of a female
4. Prestimulation of bulls increases their sexual response
5. Competition among bulls can increase their sexual response

Methods. Many procedures have been used to assess sex drive in bulls and other male livestock. Although the easiest method would seem to be observations in the breeding pasture or paddock, in practice this approach has been disappointing, at least in terms of repeatable, quantitative results. In the absence of successful indirect testing methods, the generation of such results at present requires use of a structured, pen-type testing regimen. Several such systems for the assessment of sexual behaviors in the bull are described in Box 13-18. With the libido score test, prestimulated bulls are introduced to the pen containing mildly sedated, restrained females at a BFR of 2:2 and observed for 10 minutes. Eleven categories have been described (Box 13-19).

Fertility Relationships. Cattle fertility is a multifactorial trait, influenced by both male and female factors. From the male aspect, there is good evidence that bull libido is one of the more important contributing factors. For example, in one study, better first-cycle pregnancy rates were obtained in heifers mated with higher-serving-capacity bulls than in those mated with bulls of low serving capacity (Blockey, 1978b). More recently, differences in pregnancy rates were demonstrated between high-, medium-, and low-serving-capacity Hereford bulls (Blockey, 1989). Other studies have shown advantages in herd fertility for bulls with higher sex drive (Chenoweth, 1997). Close relationships were reported between bull rankings for fertility, libido score, and testosterone response to GnRH (Post et al, 1987). In Texas one study showed that bull libido assessment provided greater prediction of bull fertility than did semen assessment alone (Smith et al, 1981). With the use of multi-sire mating and progeny identification by blood typing, the number of services performed in libido–serving capacity tests was positively correlated with fertility up to a certain level (approximately four services), above which fertility actually declined with subsequent services (Coulter and Kozub, 1989).

However, other studies have revealed poor or inconclusive relationships between bull libido–serving capacity assessment and herd fertility or pasture performance

BOX 13-17

Sperm Morphology Categories

PRIMARY SPERM ABNORMALITIES
Head abnormalities
Midpiece abnormalities
Proximal droplets
Strongly coiled tails
Double heads–midpieces
Acrosome abnormalities

SECONDARY SPERM ABNORMALITIES
Loose normal heads
Loose, folded acrosomes
Abaxial tails
Simple bent tails
Distal droplets

OTHER CELLS IN SEMEN
Epithelial cells
Erythrocytes
Medusa cells
Sperm precursors
Double heads and midpieces
Round cells
White blood cells

The minimum recommended threshold for bovine sperm morphology is 70% normal cells.

BOX 13-18

Assessment of Sexual Behaviors in the Bull

REACTION TIME
Reaction time is defined as the time elapsed between male cognition of an appropriate stimulus and the first copulation, or ejaculation.*

SERVING CAPACITY
Serving capacity is a test procedure that involves the testing of groups of prestimulated bulls with restrained, nonestrus females, at a bull-to-female ratio of 5:3 or 5:4. The number of services achieved by an individual bull within a prescribed period (10 to 40 min) is recorded as his serving capacity score.†

LIBIDO SCORE
A scoring system has been developed that describes increasing levels of sexual activity of bulls under specified test conditions, usually within a pen or dry-lot. These conditions have varied from use of unrestrained, estrus-induced females, to restrained, nonestrus females.*

*Chenoweth PJ: *Theriogenology* 16(2):155-177, 1981.
†Blockey MA: *Theriogenology* 6:393-401, 1976.

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BOX 13-19

Libido Score and Sexual Behavior

Libido score	Sexual behavior
0	No sexual interest
1	Sexual interest shown once only
2	Sexual interest shown more than once
3	Active pursuit–persistent interest
4	One mount or attempt; no service
5	Two mounts or attempts; no service
6	Three mounts or attempts; no service
7	One service; no further sexual interest
8	On service; continued interest
9	Two services; no further sexual interest
10	Two services followed by further sexual interest, including service

Chenoweth PJ: *Theriogenology* 16(2):155-177, 1981.

(Chenoweth, 1997). In some studies, although higher-libido bulls serviced more often and serviced more females than did lower-libido bulls, more pregnancies did not result (Boyd et al, 1989; Farin et al, 1989; Godfrey and Lunstra, 1989).

Such apparently contradictory findings may occur due to differing approaches and methodologies. In some trials, bulls were not placed under sufficient breeding stress to demonstrate differences, which may have been more apparent with use of higher BFRs or shorter breeding periods. In addition, bulls of potentially low fertility were excluded from cooperative breeding trials. Factors associated with BSE (scrotal circumference, sperm motility, and sperm morphology) can separately influence fertility and are apparently not linked with sex drive. Even though bulls may be superior in one trait, their fertility can be compromised by a deficiency in another. This was illustrated in one study (Farin et al, 1989) in which 92 beef bulls were placed both into satisfactory and questionable BSE categories, as well as into high (score 9 to 10) and medium (score 7 to 8) libido categories before single-sire mating with groups of estrus synchronized heifers. Here, pregnancy rate was 9.1 percent higher for satisfactory BSE bulls compared with those in the questionable BSE category, but it did not differ between bulls of high and medium libido score even though high libido bulls serviced more females and served more times than did medium libido bulls. This paradox apparently occurred because a lower percentage of serviced females in the high libido group became pregnant than in the medium group. Here, differences between bulls in sex drive were clearly masked by differences in their BSE components.

The ability of bulls to service females is related not only to their inherent sex drive but also to their mating ability. Problems in mating ability may be due to a number of physical and pathological causes, including skeletal and penile abnormalities (Chenoweth, 1983). Here, a libido–serving capacity type of test procedure can be a valuable tool in helping to detect such problems.

Factors Influencing Bull Sexual Performance

Age and Rearing Effects. Age and/or experience of bulls can influence their mating ability and thus their perceived level of sex drive. Mating ability appears to have a learning component in bulls. In young, tropical beef bulls, libido score increased with bull age between 16 and 31 months of age (Perry et al, 1990). Bull age affected sexual behavior traits in crossbred bulls, with yearling bulls showing lower libido and a higher proportion of mounts than did older bulls (Coulter and Kozub, 1989). In Florida, sexual performance assessments generally increased with age in young (12 to 24 month) *Bos taurus* bulls, although not in *Bos indicus* bulls (Chenoweth et al, 1996). The latter group, however, displayed a lower level of sexual activity than did the former. More information is needed to differentiate the effects of age and experience on bull sexual behavior from those resulting from environmental and managerial influences. In this respect, prolonged nursing was considered to retard, or compromise, the expression of normal sexual behavior in Angus bulls (Couttie and Hunter, 1956), as has feeding high concentrate levels in crossbred bulls (Hentges, 1967). Negative relationships have been obtained between sex drive and production traits (ADG and final test weight) in yearling beef bulls in one study (Ologun et al, 1981), whereas underfeeding had no adverse effects on bull sexual behavior in another (Wierzbowski, 1978). Zebu bulls raised on open range exhibited slower sexual responses compared with those reared more intensively (McFarlane, 1974), although no permanent sexual inhibitions have been attributed to rearing methods in bulls. It is, however, possible that temporary sexual inhibitions in bulls may compromise pregnancy rates in herds that have restricted breeding seasons (Chenoweth, 1981).

Social Effects. Social ranking of bulls within groups can influence their sexual activity (Chenoweth, 1997). Social dominance was positively associated with calf crop in several multi-sire breeding studies in northern Australia in which paternity was established (McCosker et al, 1989; Holroyd et al, 1998). Social dominance is expressed more strongly and linearly in older bulls (e.g., those 3.5 to 4 years of age or older) and appears to be more related to seniority than to age or body weight (Blockey, 1979). It has been suggested that the effect of social interactions among bulls on herd fertility may be greater when BFRs are low and competition for females is high (Blockey, 1979).

Dominance rank was negatively correlated with sex drive in one study with yearling bulls (Ologun et al, 1981). If dominance and sex drive are different traits, then the dominant bull (or bulls) could impair herd fertility both through failure to service females and also by preventing less dominant bulls from serving. This apparently occurred in at least one study (McCosker et al, 1989). Such effects are probably most evident when older and younger males are combined in the breeding pasture (Blockey, 1979), although mixing different bull genotypes may cause similar effects (Chenoweth, 1991).

Social effects may benefit bull sexual behavior. Such an effect was observed in one study in which greater sexual activity occurred when young, inexperienced bulls were tested in groups (three to five) than when tested individually. Similarly, yearling bulls of higher serving capacity achieved more services in double-sire tests than when tested alone (Godfrey and Lunstra, 1989). Beneficial social effects on bull sex drive expression include the observations that both prestimulation of bulls can positively affect sperm harvest (Chenoweth, 1983), and both prestimulation and competition can positively influence libido test results (Chenoweth, 1994b).

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Genetic Effects. Bulls of dairy breeds may be more sexually active than those of beef breeds, and *Bos taurus* bulls generally show higher, and less variable, levels of libido in test settings than do those of *Bos indicus* breeds (Chenoweth, 1997). A number of such breed differences are probably attributable either to genotype-environment influences or to breed variability in response to testing procedures. In studies in northern Australia, Brahman and Brahman crossbred bulls obtained the lowest libido scores, Africander bulls and their crosses achieved the highest, and European bred bulls were intermediate (Chenoweth and Osborne, 1975; Perry et al, 1991). In U.S. studies, higher sex drive scores were also obtained with *Bos taurus* bulls than with *Bos indicus* bulls (Hardin et al, 1981; Randel, 1994). Despite such results, a comparison of trials in which bulls were placed with estrus synchronized females indicated that *Bos indicus*–derived bulls were as efficient as European breed bulls in detecting, serving, and impregnating estrus females, despite a lower service rate (Chenoweth, 1994b). This discrepancy may be explained in part by observations that *Bos indicus* bulls tend to be selective and shy breeders, and that they generally do not perform well in pen tests to assess sex drive (Chenoweth et al, 1996), even though they can be very active and efficient detectors of estrus in the pasture. In Florida *Bos taurus* (Angus, Hereford) bulls obtained superior results in sex drive tests compared with tropicalized *Bos taurus* (Senepol, Romosinuano) bulls, with *Bos indicus* (Brahman, Nellore × Brahman) bulls generally obtaining the worst results (Chenoweth et al, 1996). Here it was suggested that commonly used testing procedures for sex drive may disadvantage *Bos indicus* bulls. Modifications that have been suggested in attempts to improve the performance of such bulls include the use of unrestrained estrus females and the avoidance of extraneous distractions during the test (Chenoweth, 1986).

A number of studies indicate that strong microgenetic influences occur with bull sex drive. In Scandanavia monozygous twin bulls raised on differing nutritional regimens displayed greater similarity in mating behavior and temperament within pairs than between pairs (Bane, 1954), suggesting strong genetic influences on these traits. Paternal half-sibs of Swedish bulls differed significantly in libido with greater variation between sire-son groups than within them (Hultnas, 1959). Studies showing that cross-bred bulls generally exhibited higher sex drive in pen-tests than did their parental purebreds indicate that genetic effects, in this case heterosis, influence bull sex drive (Chenoweth and Osborne, 1975; Perry et al, 1990). In Colorado, line of breeding (inbred lines or crosses among inbred lines) was an important source of variation in bull sex drive, indicating that lines had been selected or differentiated previously on the basis of sexual behavior (Chenoweth et al, 1977). Similarly, differences in libido scores were observed between breeding lines and sires-within-lines in young bulls of British breeds (Ologun et al, 1981). Here, high sex drive was not synonymous with either superior production traits (ADG or final test weight) or high social ranking. Sire strongly influenced serving capacity in young Angus bulls (Boyd and Corah, 1988). A number of studies have indicated that measures of traditional breeding soundness criteria, such as scrotal circumference and semen traits, are not significantly correlated with sex drive estimates in bulls (Chenoweth, 1997), which suggests that these are separate traits. A heritability estimate of 0.59 ± 0.16 was obtained for serving capacity in a study of 157 paternal half-sib bull groups in Australia (Blockey, 1978a). In this study the inclusion of bodyweight as a covariate did not alter the result, and serving capacity was not associated with temperament rating.

Pitfalls in Testing Bull Sex Drive. Successful testing of bulls for libido and mating ability requires careful planning. The following list represents some of the pitfalls that may be encountered in testing procedures that use restrained, nonestrus, females:

1. Testing of bulls that are excessively apprehensive or agitated. Precautions should be taken to handle cattle quietly and to avoid unnecessary distractions during the test.
2. Testing of bulls immediately following their subjection to other procedures such as EEJ, vaccination, and parasite control measures.
3. Testing under adverse weather conditions, such as in extreme heat, cold, or inclement weather.
4. Testing of bulls in groups in which one or more bulls are markedly dominant, such as with mixed-age groups of bulls. The exposure of only two bulls to test at a time, and subsequent retesting with a different bull, helps to minimize this problem. It should be noted, however, that a dominant bull can exert an inhibitory effect from a distance (e.g., from an adjacent pen). It is also recommended that stimulus females be located at an appropriate distance from each other (5 m or more).
5. Use of inadequate stimuli. Restrained females should be incapable of excessive movement, or some bulls may be deterred. Overly restless or agitated females should be replaced. The service crates used should not impede mounting and service.
6. Spreading of venereal diseases. Every precaution should be taken to ensure that diseases such as vibriosis and trichomonosis are not transmitted by such procedures.

Welfare concerns with such tests have been expressed, especially in instances where they have been conducted without due care. Guidelines for conduct of libido–serving capacity testing of bulls are discussed in the section on welfare considerations. In addition, research is ongoing into alternative ways of obtaining comparable information.

Alternative Assessment Procedures. The indirect determination of bull libido (e.g., through blood hormone levels) is an attractive proposition, since it could reduce or eliminate the time, labor, and esthetic or welfare concerns that might occur with current methods of assessing sex drive in bulls. It would also allow assessment of bulls that, for inexplicable reasons, do not give a good response in such tests. However, attempts to link either sporadic or sequential LH or testosterone (T) levels with bull sex drive have been generally disappointing (Chenoweth, 1997), probably because of the episodic nature of hormone release and the inhibiting effects of handling or restraint of the animal. By inducing LH or T release with parenteral administration of gonadotropin-releasing hormone (GnRH), there is potential to avoid some of these difficulties. In one study (Post et al, 1987), a significant relationship occurred between induced T levels and bull fertility; in another (Perry et al, 1990), positive relationships were obtained with induced LH levels. However, other studies have obtained disappointing results when attempting to relate GnRH induced levels of testosterone or LH with bull sex drive (Byerley et al, 1990; Chase et al, 1997).

Composite Assessment Systems for Bulls. A number of factors influence bull fertility, including BSE values and behavioral factors such as dominance and libido, and these do not always complement each other. Attempts have been made to combine a number of these factors to best predict bull performance. Perry et al (1990) assessed a number of traits in young tropical beef bulls at varying intervals from single-sire matings. The traits assessed included BSE values, sex drive (libido and serving capacity), production traits (ADG and body weight), and LH and T

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responses to GnRH. A stepwise regression procedure was used to select the most suitable combinations of traits highly correlated with pregnancy rate. Fertility indexes were calculated from this analysis. The fertility indexes so obtained were, in general, highly predictive of pregnancy rate, even at 11 months before mating. The lowest correlation was the one obtained at the examination just before breeding ($r = 0.45$, <0.05) when the only trait included in the index was libido score. Genotype differences had little influnces on these indexes. Overall, the most important measures were GnRH–induced LH levels, testicular volume, libido, and body weight. Interestingly, these factors are derived from separate entities known to influnce bull reproductive performance (e.g., sex drive, endocrine status, and sperm production).

Coulter and Kozub (1989) used a regression model to predict bull fertility in multisire breeding in which paternity was determined by blood typing. Best relationships with fertility were obtained with scrotal circumference, backfat, sperm morphology (particularly primary abnormalities), and sex drive. In yearling bulls the model accounted for 37% of the variance in bull fertility; in 2-year-old bulls it accounted for 22%. A study conducted in northern Australia also used paternity estimates to predict the fertility of bulls in multisire breeding systems (Holroyd et al, 1998). Here, the most "successful" predictors of calf crop were percent normal sperm and social dominance, with scrotal circumference and an assessment of sexual behavior (mounts plus services) also showing some predictability. Thus it seems as if the best prediction of bull fertility is obtained when bulls are assessed for a number of traits, including sex drive. The development of fertility indexes, which combine a number of important traits, should improve predictive ability. Recommendations for bull assessment and management are shown in Box 13-20.

ARTIFICIAL INSEMINATION AND ESTRUS SYNCHRONIZATION PROGRAMS

AI is a proven tool for promoting genetic progress in livestock. With cattle, the dairy industry has adopted this technology wholeheartedly, whereas the beef industry has been less receptive (at least in the Americas and Australasia)—despite evidence that many economically important traits in beef cattle are relatively highly heritable, and that AI is the best means to rapidly exploit genetically superior sires (Patterson, 1999). It is also despite evidence that an effective genetics program, managed with AI, is cost effective, with an estimate of $7 to $30 increased returns per cow (Toombs, 1996). In the United States, the percentage of beef operations using AI has increased slightly from 5.4% in 1992 and 1993 to 7.1% in 1997 (NAHMS, 1998b). The reasons for this relatively low adoption rate vary. However, contributing factors include unwillingness to change management practices, fear of the unknown, and a perception that an unacceptable amount of effort is involved. A certain amount of effort is, of course, necessary. This includes attention to aspects such as identification and management of adequate numbers of "eligible" females, animal confinement, estrus detection, breeding facilities, time constraints, and AI technique (Chenoweth et al, 1980). At least some of these constraints may be countered with estrus synchronization. However, producers still have reservations about the cost and effectiveness of AI-synchronization programs, particularly in commercial herds run under extensive conditions. Examples of failed programs are common. This section outlines a number of options available for synchronization programs in beef cattle, as well as managerial precautions to help prevent failure. Veterinarians should consider planning programs with their clients well ahead of breeding. For larger beef operations, particularly those that are conducting AI programs (either with or without synchronization) for the first time, prior training of personnel in all aspects of such programs is strongly recommended. Preliminary planning should commence well before the breeding season in question. As well as personnel training, facility suitability and estimated numbers of eligible females should be considered. Semen should be ordered early, and from a reliable source, as should liquid nitrogen equipment and synchronization products. If necessary, frozen semen should be checked by a competent laboratory before the commencement of breeding. Related considerations include the following topics.

BOX 13-20

Recommendations for Bull Assessment and Management

- Select sound bulls with good expected progeny differences
- Perform breeding soundness evaluation of all bulls every year
- Conduct a libido–serving capacity test where feasible
- Test older bulls for vibriosis and trichomonosis before breeding
- Vaccinate all bulls before breeding; use homogenous groups of 2- to 3-year-old bulls
- For yearling bulls, use a higher bull-to-female ratio (1:15-20)
- Regularly monitor bulls in breeding pasture

General Considerations

Female Selection

Animals selected for AI-synchronization programs should be those that are good candidates for successful breeding. For heifers, this means those that have achieved target weights for their breed type and those that are cyclic. Use of reproductive tract scoring (Anderson et al, 1991) is effective in determining the latter. Cows require an adequate postpartum interval, which varies with nutritional status, as previously discussed. In addition, some breed differences occur, with *Bos indicus*–type cattle often requiring a longer interval than *Bos taurus* cattle. Several stratagems to help reduce this interval may be considered. These include weaning stratagems such as temporary calf removal and once-a-day suckling as well as biostimulation (Chenoweth and Spitzer, 1995; Spitzer, 1998). Females that are poor candidates for AI-synchronization include those in poor body condition, those with calving problems, and those that have suffered setbacks or illness.

Herd Health

AI programs, with or without synchronization, should only be attempted in herds that have a good herd health program. The best breeding programs will be unsuccessful if they have to compete with infertility diseases such as vibriosis and trichomonosis. Protection should be provided against abortion-causing diseases such as leptospirosis, IBR, and brucellosis (where applicable). Herd health considerations extend to the source of semen. Semen, whether frozen, chilled, or fresh, should come from sires of known herd health and from an organization that maintains good health

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and sanitary requirements. In the United States, this is ensured by using frozen semen from organizations affiliated with CSS.

Facilities

Effective artificial breeding programs require good facilities, including those for congregating cattle, feeding them if necessary, observing estrus, and breeding. For breeding, an enclosed breeding chute or crush has advantages in reducing animal stress. For synchronization programs, prior calculation should be made of the maximum number of animals that can be handled (i.e., bred) during the breeding "window." Protection from the elements while handling semen and breeding is also an important consideration.

Animal Identification and Records

Implementation of AI on beef operations often mandates an upgrading of record keeping on the property, as well as improvement in animal identification systems. Animal identification should be read easily from both sides at a distance and be unambiguous. A number of effective identification systems are available, varying from electronic chips to legible ear tags and paint marks. Record-keeping systems should keep tabs on which females were bred to which bull and when. Other information, such as estrus signs, ease of AI, and any other relevant comments are also helpful.

Stress Reduction

Stress reduces reproductive success, with this probably playing a greater role with AI/synchronization programs than with natural breeding. Stress is increased by environmental factors, such as excessive heat, cold, and unstable weather. It is also increased when animals are handled roughly, such as when they are driven a long distance and subjected to dogs, whips, and electric prods. Stress is reduced when animals are conditioned to the facilities, they are handled gently, and breeding is performed in an enclosed breeding box.

Technicians-Inseminators

Technicians-inseminators are a potential problem area with beef artificial breeding programs, since technicians vary in experience and technique. For synchronization programs, the inseminator should have had recent experience in successfully breeding large groups of females within a restricted period. Owner-inseminators who have had limited experience under such conditions may be disappointed with their results.

Estrus Detection

Cowboys (and stockmen) are often surprisingly unaware of the finer details of effective estrus detection, in contrast with their dairy colleagues. Here, some prior sensitization might be in order, whether or not estrus detection aids are used. People delegated to observe estrus should be both knowledgeable and motivated. Estrus detection is best observed in smaller groups of animals in a confined area such as a feedlot or trap. Best time to observe is first thing in the morning and late afternoon-early evening. At least 30 to 60 minutes of uninterrupted time should be devoted to this task on each occasion. Estrus detection aids add to the efficiency of estrus detection in most types of programs. These run the spectrum from tail paint to K-Mar heat mount detectors and Heat-Watch (electronic pressure-activated devices that transmit data to a recording device). They may be used with teaser bulls or, equally effectively, with androgenized cows (Burns and Spitzer, 1992).

Calving

Calving after a successful synchronization program should occur within a compressed time period. If all females are bred on the same day, most calves will be born over a 2-week period, with a 4- to 5-day period of maximum activity. Preparations should be made for an adequate calving watch over this period, with personnel and facilities being made adequate to handle emergencies. It is helpful if sires used for heifer breeding are selected for calving ease.

Synchronization Programs

Synchronization makes more cows available for AI, shortens the period of AI, reduces estrus detection effort, allows more efficient scheduling of breeding and calving, and can allow females to get pregnant earlier. However, although hormonal means to effectively group estrus in beef females have been marketed for some time, beef producers have been slow to adopt (Patterson, 1999). Selection of a "best" method for a particular operation depends on a number of factors. Product cost is important, but other considerations include overall duration of program, number of cattle handling opportunities, and cost of semen.

Early methods to control the bovine estrus cycle used exogenous progesterone to prolong the luteal phase of the estrous cycle or to establish an artificial luteal phase (Patterson, 1999). These programs suffered from variable and poor results. When prostaglandin (PG) became available, this rapidly became the preferred product for synchronization programs. Administration of PG alone causes lysis of the corpus luteum (CL) in cycling females, with subsequent estrus. However, this method is ineffective in females that do not have an active CL. Absence of a CL may occur in animals that are acyclic, and in those at the "wrong" phase of the estrous cycle when PG is administered. A single injection of PG into a group of females that are all cycling causes an approximate 75% to 80% estrus response rate. Several approaches have been used to improve this response. For example, the "Moody system" is a single-injection system that has some advantages for beef producers (Chenoweth et al, 1980). This works as follows:

Days 1 to 5: Conventional AI program of heat detection and insemination.

Day 6: At this juncture, a decision can be made whether to proceed depending on whether detected estrus has been satisfactory over the past 5 days. If so, the remaining unbred females can be given an injection of PG.

Days 6 to 11: Breeding of estrus females.

Days 27 to 33: Rebreed synchronized females that did not settle on the first heat.

This system has the advantages that animals require only one PG injection, and it incorporates a "fail-safe" feature if results are not promising after the initial breeding period.

Compared with a single injection of PG, a two-injection regimen of PG given 11 to 13 days apart increases estrus response rates such that virtually all females should show heat within a 5-day period. Heat detection, however, is still required.

A system that allows breeding either at detected or timed heat is the Syncro-Mate B program (SMB) or Crestar. This

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combines the use of a progesterone and estrogen in an ear implant, usually left in place for 9 days, in conjunction with an injection of estrogen at implant insertion. This system has the advantage that it may be used with all cycling females, regardless of where they are in their estrous cycle, and it may also stimulate cyclicity in some subcyclic females. If implants are inserted on Day 0, and removed on Day 9, most responding females will show heat between Days 10 and 13. For fixed-time insemination the best time is 48 to 54 hours following implant removal. In lactating females, calf removal between implant removal and start of breeding (48 hours) can improve estrus and pregnancy responses. However, this product is not currently available in the United States.

Controlled Intravaginal Drug Releasing and Progesterone-Releasing Intravaginal Devices

Both controlled intravaginal drug releasing (CIDR) and progesterone-releasing intravaginal devices (PRIDs) are controlled, internal, drug-releasing intravaginal devices used to synchronize estrus in cows and heifers. The CIDR contains 1.2 g of progesterone, whereas the PRID contains 1.55 g progesterone plus 10 mg of estradiol valerate. A common protocol is to insert the CIDR, give an injection of PG on Day 6, and remove the device on Day 7. Following removal of the CIDR, estrus should lead to responding females within 1 to 3 days. Breeding is conducted in conjunction with estrus detection. This method has shown some ability to stimulate cyclicity in acyclic females also. PRIDs are generally left in for 12 days, although this can be shortened to 8 days if a PG injection is given on Day 7. Neither product is presently available in the United States, although CIDRs are undergoing the regulatory process.

Melengestrol Acetate/Prostaglandin

An inexpensive and useful synchronization system that has particular advantages for heifer synchronization in range-type herds is a system that uses melengestrol acetate (MGA) in conjunction with PG. MGA, a progestogen that can be administered as a top dressing or mixed in feed, prevents estrus. Cessation of feeding causes cyclicity, although the first resultant estrus is relatively infertile. Thus breeding is usually delayed until the second cycle, which is further synchronized with PG. A common protocol is to feed MGA for 14 days, as follows:

Days 1 to 14: Feed 0.5 mg MGA/head/day.
Day 15: Stop feeding MGA. Responding females should come into heat over the next 7 days.
Day 31: Inject PG. Responding females will come into heat over the next 5 days.
Days 32 to 38: Inseminate according to estrus.

This system (without the use of PG) has also been used effectively with natural breeding (Patterson et al, 1990).

Ovsynch, Cosynch, and Select Synch

Programs have been devised that use various combinations of GnRH with PG, in attempts to synchronize follicular dynamics, and that facilitate fixed-time insemination. Different variations on this theme have been termed *Ovsynch, Cosynch,* and *Select Synch* (Patterson, 1999). For postpartum beef cows, Cosynch and Select Synch have received most attention, whereas Ovsynch has been used most with dairy cows. With Cosynch, GnRH is given on Day 1, PG on Day 7, and then GnRH is given on Day 9 to coincide with AI breeding. Select Synch is a program that uses conventional estrus detection. GnRH is given on Day 1, PG on Day 7, followed by estrus detection and AI. Results with these programs exceed those obtained with a two-injection PG program (Patterson, 1999).

Synchronization Programs with Natural Breeding (Bull-Synch)

A number of producers are successfully using estrus synchronization programs in conjunction with natural breeding. Successful Bull-Synch has been used with PG, SMB, and MGA programs. Although Bull-Synch does not confer the genetic advantages of using superior AI sires, it does have other advantages, such as less overall effort and cost than AI-synchronization programs, including delegation of estrus detection duties to the bull. Such programs can be useful as an interim step toward a full AI-synchronization program by facilitating animal grouping and by refining synchronization protocols (Pexton et al, 1989). For some, this represents a useful heifer-breeding program in its own right. A successful program will achieve results at least as good as for AI (Pexton and Chenoweth, 1977), with most breeding occurring over a 2- to 3-day period. During that time, an active bull will serve many times (e.g., an average of 55 times in 30 hours in the Colorado trials). Such work rates emphasize the importance of using sound, agile bulls that have passed a breeding soundness examination. Some programs have achieved good results by removing females after they have been serviced once, although optimum fertility usually requires several services.

Guidelines for the successful conduct of a Bull-Synch program include the same as those for a conventional AI-synchronization program, with the addition of the following considerations;

1. Bulls should be preassessed for breeding soundness. A libido–serving capacity test may also be useful in selecting the best bulls for this task (Farin et al, 1989).
2. Breeding is best done in a small pasture or lot.
3. BFRs may be between 1:10 and 1:30, although 1:20 is advised (Patterson, 1999).
4. Single-sire breeding is preferable.
5. The breeding "season" should be regularly monitored.

Economics of Artificial Insemination Breeding Systems

The cost of an AI breeding system is determined by a number of factors, including the number of times cattle are worked (thus influencing labor costs), the cost of the synchronization products, and the cost of semen. Benefits include genetic improvement plus improved management spin-offs such as earlier, more concentrated calving. Costs are also associated with natural breeding. A comparison between different systems has been made based on 1998 U.S. prices (Table 13-36) (Hogan, 1998).

Biostimulation

Biostimulation is a term used to describe the stimulatory (positive) effects of a male-on-female reproductive behavior or response. This can include effects on estrus, ovulation, or pregnancy. Although best recognized in species such as sheep, it is evident that biostimulatory effects also occur in cattle. A number of studies have shown positive effects of bull presence on interval to estrus following parturition in cows, whereas inconsistent results occur with such effects on heifer puberty (Chenoweth and Spitzer, 1995; Spitzer, 1998). With the latter, interactions appear to occur with nutrition and other environmental factors, as well as unknown factors. The mechanism(s) for biostimulation is/are largely unknown. However, it is not restricted to males only since androgenized females can be equally effective (Chenoweth and Lennon, 1984; Burns and Spitzer, 1992). With postpartum cows biostimulation appears to be most effective before Day 60 after calving. It thus appears to have particular

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TABLE 13-36

Relative Cost of Natural Versus Artificial Breeding

Method	Natural Breeding*	Cosynch	Syncro-Mate B7	Traditional Artificial Insemination (AI)
Bull cost	$2750	—	—	—
Cost/Pregnancy	$39.35	$34.67	$25.42	$45.00

Based on 60% AI success.
*Bull bred with 30 females at 92.5% pregnancy rate. Bull costs include salvage, depreciation, maintenance, and opportunity costs. AI-synchronization costs include product and labor.

advantages for use with late-calving cows and for use in conjunction with AI programs (Spitzer, 1998).

RECORD COLLECTION AND MANAGEMENT

To achieve optimum performance, both production and financial, records of production and costs are necessary. In the United States, a large proportion of cow-calf producers report that they keep some sort of records, but most are hand written. Computer records were not commonly kept except in herds greater than 300 head (NAHMS, 1997a). In a survey of producers in the Northwest that regularly used a veterinarian for herd services, 64% reported that they kept production records. However, when asked for specific production or health measures, they were only able to provide estimates, which suggested that their records were not in an accessible form (Sanderson and Gay, 1996).

Hand-written records have limited use because of the difficulty in summarizing and analyzing them. In and of themselves, records are data on the productivity of the farm. They must be summarized and analyzed in order to turn the data into information useful for guiding management decisions. Analysis of data is accomplished most efficiently with the use of a computer. Once hand-written records are collected, half the work is done and entry of the data into a computer database will dramatically increase its use. Day-to-day recording of data is best collected in a pocket diary. Daily births, morbidities, mortalities, and treatments can be recorded and entered into the computer database later. Data from pregnancy examination may be collected directly into the computer database at "chuteside." Future improvements in data acquisition may increase the ability to input data directly to the computer at the time of the management event.

Quality databases are currently commercially available for cow-calf record management and analysis (e.g., Cow-Calf 5, Cowsense, or CowBoss). These may be purchased by individual producers to keep records on their own herds or by veterinarians to keep records in multiple herds. In either case the veterinarian should be involved in the analysis and interpretation. Anonymous comparison of production data and costs among herds in a practice or region may be useful in identifying production inefficiencies and opportunities. Summary data on production and economic measures in cow-calf herds are available (e.g., CHAPS, SPA) (Spire, 1991). Identification of "production practices" that are profitable for cow-calf producers must be measured at the herd level and thus will require production data on a large number of herds. The current move in the U.S. cow-calf industry toward production-marketing alliances may provide an opportunity for comparison of production information on large numbers of herds. With additional training in database management and data analysis and interpretation, veterinarians could play an important role in this expanding area.

Opportunities for veterinarians to assist producers with production and financial records are extensive. SPA data highlight the importance of controlling costs in beef cow-calf herds for profitability (McGrann and Wikse, 1996). Indiscriminate cost cutting has the potential to decrease production return more than the cost savings and to decrease net return. Informed decisions to optimize production level and maximize net income can only be made on the basis of records to identify input costs and production response for the individual herd. Whereas generic regional production and financial data provide a good starting point, actual optimum production level is unique to each herd because of differences in input costs and environment.

The ideal record system for the cow-calf enterprise facilitates collection of the necessary data to allow informed decision making. It does not collect excessive, unnecessary data that waste time, cost, and effort without improving decision making. The proper balance between these two principles is sometimes difficult to achieve, and it differs between herds. Guiding principles in deciding what records to keep on an individual ranch should include the following:

1. Ability to articulate the proposed utility of the data to be collected. If you cannot state for what the proposed data will be used, it is probably not worth the time and expense to collect it.
2. The desire of the producer to keep and use records. Recording a small number of the "most" important records may be helpful and effective in showing the producer the value of records. Overwhelming the producer with too much "paper work" will likely doom the record-keeping effort to failure.

Four questions are helpful in identifying the record-keeping needs of the operation:

1. What are the sources of revenue for the operation?
2. What are the sources of expense for the operation?
3. What are the suspected biggest sources of lost revenue (failure to conceive, low rates of gain, marketing errors, health losses)?
4. What are the suspected biggest sources of excess cost (wasted or spoiled winter feed, wasted or ineffective vaccine or antibiotics, machinery purchase and maintenance)?

Quantification of answers to the third and fourth questions is the purpose of record-keeping systems. Ranchers and the veterinarians who serve them would do well to write out the answers to these questions, then write out the components of their production system directly related to each

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question. At that point, they are ready to begin evaluating record-keeping packages for how well they satisfy their specific needs. Financial and economic records collection has been covered in the section devoted to standardized performance analysis and is not covered here. This section concentrates on production records.

The economic level of record keeping at which cost of record keeping equals the economic return is unknown and likely variable from ranch to ranch. Considerable research is needed on the economic value of particular production records. The goal of the record-keeping system should be to identify and quantify sources of income as well as expense for the operation. Once these records are in place, practitioners can begin to identify the areas of significant lost revenue resulting from decreased production or excess cost. Records kept should be evaluated in light of these goals.

The records that we keep are primary source data or the raw data of the operation as it occurs. This primary source data would include, for example, the pregnancy status of the individual cow or the treatment of the individual calf. From this primary source data, we calculate useful indices of production that can inform decision-making. These production indices would include pregnancy rate, morbidity rate, calf crop, etc. The primary source data must be collected in a reliable way to ensure its utility. This requires that the database information system be structured in a way that reflects the production process.

A minimum production database of records should provide the ability to track production indexes at the herd level. The minimum collection of primary records would include the following:

1. *Number of cows and heifers in the herd at the beginning of the fiscal year.* For any record system an accurate inventory of production units throughout the year is essential. Without accurate inventories, the calculated production indexes are meaningless.
2. *Number of cows and heifers exposed to be bred.* This is the number of cows and heifers supported in order to produce the weaned calf crop.
3. *Transfers of pairs or pregnant females in or out of the herd.* Transfers must be accounted for to keep inventories correct and to make calculated production indexes meaningful.
4. *Total number of calves weaned.* This is the aggregate calf production of the herd.
5. *Total pounds of calf weaned.* This is the aggregate production of the herd in pounds.
6. *Total price received for weaned calves.*
7. *Total acres used for grazing and raised feed.*
8. *Treatment and processing records of groups to facilitate quality assurance.* These records are essential to ensure that chemical and physical defects are avoided. These records should include the date of procedures performed, products used, lot number, administration route and site, and frequency of needle changes (see Fig. 13-12 on p. 572). Records kept here will be defined by the goals of the quality assurance program designed to meet the requirements of the operations customers.

These records allow the calculation of herd production levels of the following:

1. *Calf crop.* Total number of calves weaned divided by the number of cows exposed to be bred. Calf crop includes losses from infertility, early embryonic death, abortion, stillbirth, and calf death from birth to weaning. As such, it identifies depressed production without identifying the specific cause. Identification of the specific cause requires additional primary records targeted to each area of loss.
2. *Pounds of calf weaned per cow exposed.* Total pounds of calf weaned divided by the cows exposed to be bred—another important calculated production index. Pounds weaned per cow exposed include loss from all areas included in calf crop and losses resulting from depressed weight gain in calves.
3. *Pounds of calf weaned per acre of land used for grazing or feed production.* Total pounds of calf weaned divided by total acres used for grazing or raised feed—a measure of the efficiency with which grazing and forage producing land is used.

Additional primary source data allow more exact tracking of production level and specific causes of production depression and inefficiency.

1. *Individual cow and calf identification.* The basis of tracking individual performance of cows in the herd and culling based on that performance.
2. *Individual cow and heifer pregnancy status.* Pregnancy percentage provides an index of the breeding efficiency of the herd. It includes failure to conceive, early embryonic mortality, and, depending on the time of pregnancy examination, early- to mid-term abortions. Along with BCS at breeding and pregnancy, it provides an estimate of nutritional effects on fertility.
3. *Cow BCSs or cow weights.* Ideally at the time of pregnancy examination and before calving. They help identify potential nutritional effects on reproductive performance and groups of cattle that may need separate nutritional management.
4. *Calf birth date/Calving date.* Identify early born calves and early calving cows. When categorized by 21-day periods during the calving season to produce a calving histogram, it provides an index of fertility over the course of the breeding season.
5. *Calf birth weight.*
6. *Calving ease score.* A measure of the incidence and severity of dystocia. Along with calf birth weights, this can effectively guide the use of expected progeny differences for sire selection to control dystocia rates and optimize calf growth.
7. *Calf vigor score.* Scored at birth. It may reflect the effects of dystocia, nutritional deficiency, and infectious disease on the calf.
8. *Date of all calf deaths.* Along with calf birth date, this allows assessment of when mortality is occurring. Analysis can assess rates of stillbirths, deaths from birth to 24 hours, 1 to 28 days of age, and 28 days of age to weaning. Provides detail on when losses are occurring to guide intervention resources and efforts.
9. *Individual calf weaning weight.* Assess the production of individual cows.

A comprehensive production management information system includes additional elements such as the following:

1. *Date and diagnosis of morbidity in calves and cows.* These data allow calculation of disease-specific incidence rates. This provides additional detail on the time of losses and the effect on production to effectively guide the rational allocation of resources to prevention. Record of disease-specific rates require training of producers to validate case definitions to allow useful interpretation of the data. If rates are to be compared across herds, each producer needs to be using the same case definition—that is, all producers have to agree on what a sick calf is.
2. *Date and treatment of morbidity in calves and cows.* Useful in assessing response to treatment and providing quality assurance validation. If treatment response is to be measured recovery, retreatment and final disposition dates of all cases need to be tracked also.

The collection and tracking of calf morbidity data allow the assessment of the effects of morbidity on calf performance and the costs associated with each morbidity incident.

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Once these values are known, an appropriate amount of resources can be allocated to optimize net income. Current record-keeping databases for cow calf production are limited in their ability to track morbidity incidence but will likely improve over the next few years.

Commercially available record management programs provide "canned" reports of certain production indexes. In addition, the database can be queried to provide additional indexes that may be useful in addressing production. Proper design of the database is necessary for full use of the collected data. If the program design does not reflect the relationships inherent in the production system it models, it will sometimes fail to allow the needed analysis for decision making. The program should also be able to write records data to a file for importation into software that allows for more sophisticated analysis.

The record system chosen should be based on the desire of the producer and the level of information needed to make decisions. Collection of primary source data on an individual animal basis allows much greater flexibility in identifying areas of production depression and the likely causes of it. Financial and economic data must be kept as well in order to assess the effect of production changes on net income. Standardized performance analysis for assessment of financial and economic performance has been dealt with in more detail elsewhere in this chapter.

BEEF QUALITY ASSURANCE

Hazard analysis of critical control points (HACCP) is a process control method to identify hazards or dangers that may occur during production and identify ways to prevent them from happening. The focus is on prevention of problems rather than on detecting and removing problem animals. Beginning in January 1998, HACCP became the method of ensuring food safety in all large U.S. beef slaughter plants. By January 2000, all U.S. beef slaughter plants were required to have a HACCP plan in place. With the establishment of HACCP programs in slaughter plants, much attention has been focused on extending the concept back to the production phases of the beef industry. To some extent this is already being done at the feedlot level, although not yet by government regulation. It is only a matter of time before it is extended to the cow-calf and stocker sectors.

HACCP is a process control method developed by the Pillsbury Company in the 1960s. When NASA was planning the space program they were confronted with the problem of ensuring food safety for the astronauts during their trips. Every meal could not be tested because the very nature of the testing could cause contamination. They developed the HACCP concept to prevent food safety problems and to ensure a safe product.

The first step in implementing a HACCP program is hazard analysis (Box 13-21). This involves a thorough study of the product (beef, in this case) and the conditions, inputs, and management practices of production, distribution, and processing. Hazard analysis is used to identify the areas where something could go wrong and a food safety or quality problem could occur. Once these areas are identified, they become the guides for implementing critical control points to prevent food safety and quality problems. Management practices and activities are implemented to prevent the hazard from occurring. Finally, the critical control points are monitored to be sure the management changes are controlling risk. If the critical control points are working, the final product is very likely to be safe. This process is in place for the majority of beef slaughtered in the United States at this point. Preliminary data suggest it has been effective in reducing the incidence of *Salmonella* on ground beef by more than one third (USDA:FSIS News Release, March 9, 1999).

The concern here is the application of the program's principle to preharvest production. The feedlot industry has already begun implementation of an HACCP-like program called quality assurance critical management points (QACMP) (Box 13-22), sometimes just referred to as beef quality assurance (BQA). The feedlot industry has focused its efforts in three areas that may cause a food (beef) to be unsafe or of reduced quality: bacterial contamination, chemical residues, and physical defects. A similar approach may be useful for the cow-calf sector.

Problem Categories

Bacterial Contamination

At this point there are no known critical management points for bacterial contamination at the preharvest level (Hancock, 1997). Bacterial agents of concern include *Salmonella, Campylobacter* sp., *E. coli* O157:H7, and *Listeria*. The ecology of foodborne pathogens in the production environment is not known well enough to clearly identify any points at which the hazard could be prevented. Available evidence suggests that food and water may be impor-

BOX 13-21

Identifying Potential Safety or Quality Hazards

Identify Critical Management Points (CMPs): Points at which potential problems can be controlled or eliminated.
Establish critical limits for CMPs: Determine how to identify when a management activity is not being conducted correctly.
Establish CMP monitoring procedures: Ensure that CMPs stay within established limits.
Establish corrective actions: Corrective action to be taken when critical limits are exceeded. Includes what to do to prevent the problem from happening again.
Establish verification procedures: Testing monitoring to ensure that the system is working.
Establish record keeping procedures: Document the system is working.

BOX 13-22

Five Preliminary Steps to Quality Assurance Critical Management Points (QACMP)

1. Assemble a QACMP team and resources.
2. Describe what you raise and how it is distributed
3. Identify who buys your cattle and communicate with them
4. Develop and verify a process flow diagram (all the production steps)
5. Meet requirements for good management practices for beef quality assurance

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tant reservoirs for transmission of these agents both within and between farms. Clearly, prevention of fecal-oral transmission by ensuring clean water and feed are good management practices, but their validity as critical management points is unknown. Development of water sources to minimize fecal contamination may be useful, but the economic cost:benefit ratio cannot yet be assessed. Use of equipment for cleaning pens or corrals and then deliverance of feed without a thorough cleaning between should not occur. Further research on the ecology of foodborne pathogens may identify critical control points. Competitive exclusion or inhibition therapy and dietary modification may prove to be useful critical control points with further research. Current recommendations for prevention of bacterial defects are summarized in Box 13-23.

Chemical Residues

The beef industry has a history of dealing effectively with chemical residues, such as antibiotic, anthelmintic, and pesticide residues. Fed beef cattle accounted for 2% of violative chemical residues in 1996 (Paige et al, 1999). Control has been achieved by record keeping of individual animal treatments to facilitate adherence to withdrawal times. In the United States, use, records, and withdrawal time of all drugs must conform to Animal Medicinal Drug Use Clarification Act (AMDUCA) guidelines. The primary cause of violative residues for all classes of animals was failure to follow established withdrawal times, followed by inadequate animal identification and inadequate medical records (Paige et al, 1999). The cow-calf industry is somewhat insulated from chemical residue concerns by their temporal distance from entering the food chain. However, certain antibiotics and pesticides may lead to residues extending into the slaughter phase, most significantly gentamicin. Cull cows, however, may be slaughtered promptly after sale, increasing the risk of violative residues. Cull beef cows accounted for 10% of residues in 1996 (Paige et al, 1999), highlighting the need to increase producer and veterinary vigilance to decrease the violation rate (Table 13-37).

Drug withdrawal times should be completed before sale or shipment, or the purchaser should be notified of remaining withdrawal constraints. The Nebraska Beef Quality Assurance program prohibits the use of aminoglycosides because of their extended withdrawal time, and the American Association of Bovine Practitioners has instituted a voluntary prohibition of aminoglycoside use. Aminoglycoside withdrawal time may exceed the life of the calf even when given early in life.

Pesticide residues may occur through contamination of feeds, necessitating that feedstuffs be free of contamination. This requires records of pesticide use and adequate time before harvest to allow feedstuff residues to decline. Cooperation from suppliers is essential. Suppliers must have procedures in place to ensure residue-free product and must provide documentation. Withdrawal times following pesticide exposure may be extensive and on occasion may force euthanasia and disposal of animals. Topical organophosphate antiparasitics and pesticides should be stored securely away from all feedstuffs to avoid inadvertent contamination. Contaminated feedstuffs must be discarded.

Nonperforming cattle ("chronic poor doers") are animals requiring particular vigilance with regard to chemical residues (Box 13-24). At the cow-calf level, cull cows need to be monitored carefully to ensure drug clearance before slaughter. These animals may have metabolic abnormalities, such as liver and kidney dysfunction, that will dramatically extend withdrawal times. Screening for residues before shipment is prudent.

BOX 13-23

Prevention of Bacterial Contamination

- While no specific critical management points exist for bacterial contamination, good management practices to minimize fecal oral transmission of potential pathogens are prudent.
- Avoid fecal contamination of feedstuffs. Use separate equipment for cleaning pens and loading feed, or thoroughly wash bucket, tires, and undercarriage before using on feed.
- Regularly clean water troughs to minimize fecal contamination.
- Buy feeds from reputable suppliers; some may have quality control testing programs that may include organisms like *Salmonella*.

TABLE 13-37

Number and Percent of Residue Violations by Class of Slaughter Animal In the United States (1996)

Slaughter Class	No. of animals	Residues (%)
Bob veal	941	47
Cull dairy	647	32
Market hogs	49	2
Beef cows	191	10
Sows	8	0.4
Steers	45	2
Other	111	6

BOX 13-24

Prevention of Chemical Residues

- Establish a treatment protocol book that includes appropriate withdrawal times.
- Record all processing and treatment of animals and the associated withdrawal times. Follow Animal Medicinal Drug Use Clarification Act guidelines for drug use.
- All withdrawal times should be checked before shipment.
- Nonperforming "realizer" animals should be tested for residues before shipment.
- Store herbicides and pesticides separately from feed.
- Buy feed from reputable suppliers with quality control procedures in place.
- Collect and save a representative sample of all feeds.

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Physical Defects

Injection site lesions, bruises, hide defects from brands and parasites, and needles broken off in the muscle are examples of physical defects (Box 13-25). Significant progress has been made in injection site lesions. In 1991 the National Beef Quality Audit found that 21.6% of all top butts in fed cattle had injection site lesions. By 1997, top butt lesions had decreased to 5.6% (National Cattleman's Beef Association, 1997). Responsibility for prevention of injection site lesions extends back to the cow-calf producer. Injections given early in life cause detectable changes in muscle tissue at slaughter that reduce tenderness (George et al, 1997). In 1994 76% of cow-calf producers and 65% of veterinarians were still administering intramuscular injections in the hindquarters (NAHMS/CHAPA, 1994c). Injection site lesion data suggest this may have improved. Nonfed beef (cull beef and dairy cows) remains a problem regarding injection site lesions. To continue to control injection site lesions in all classes of cattle, products should be chosen that can be given subcutaneously in the neck area.

Any intramuscular injections should be given in the neck, never in the hind quarter, shoulder, or loin. The neck muscle is a lower-priced cut of meat, commonly ground into hamburger, and it seems less reactive to injections.

An additional physical defect is broken needles left in muscle. Animals with broken needles cannot be shipped to slaughter. Metal hubbed needles should be used and changed every 10 head or less. Bent needles should be changed immediately, rather than straightened and reused. Broken needles must be removed or the animal euthanized and disposed.

Bruising is another cause of quality defects in carcasses. One study of cull cows found bruises on 48% of cull cow carcasses, with 17% of the bruises being considered major and requiring extensive trimming (Hoffman et al, 1998). Cows originating from livestock markets conducting first point testing for brucellosis had a greater number and severity of bruises, suggesting a role of increased handling in bruise incidence. Another study suggested that rough handling in the feedlot caused increased incidence of bruising at slaughter (Grandin, 1981). Proper handling procedures and safe facilities are necessary to prevent bruising in cattle.

Role of Veterinarians in Beef Quality Assurance

The veterinarian's role in BQA is to assemble and coordinate a team to establish QACMP procedures on the ranch. This requires careful analysis of the management and procurement procedures on the ranch in order to identify any practices that could cause a quality or safety defect. The veterinarian should be pivotal in the establishment of management practices to reduce the risk of defects. This requires that the veterinarian serve as an educator to teach producers the importance of management practices to decrease quality defects. This includes proper injection procedures and sites, proper handling of cattle, and proper records and observance of withdrawal times. An emerging role for veterinarians will be in practicing, and educating producers on, prudent use of antibiotics.

A record-keeping system to monitor control points and verify their effectiveness is essential. This may include processing diagrams to indicate products used and location of administration (Fig. 13-12), as well as recording and checking of all withdrawal times before shipment. Residue data suggest that improved animal identification and records to ensure compliance with withdrawal times are still required. Veterinarians should be pivotal in continuing to educate producers and implement proper records and withdrawal plans. Management practices for storage and use of pesticides to ensure feedstuffs do not become contaminated are necessary. Animal-handling education and guidelines as well as safe and functional facilities are necessary to control bruising. The veterinarian should be involved in monitoring the QACMP plan to ensure goals are being met. Periodically the plan should be reevaluated to ensure the critical management points are effective and useful. As new information becomes available, management will need to change to most effectively control safety and quality risk.

No quality assurance program can work without the cooperation of labor and management. A key factor in the successful QACMP plan is the education and motivation of the workforce. Workers should be trained in the requirements and necessity of the components of the quality assurance plan. Managers should be made responsible for compliance with the QACMP plan and asked to sign off on records for a set of cattle before shipment. The veterinarian is essential in the training of workers to appreciate the importance of the plan and to carry it out effectively.

The beef industry is aggressively working to build an effective system of ensuring beef quality and safety. The future of the industry depends on consumers' having confidence in the safety, quality, and consistency of beef. Veterinarians should have an important role in this system that will benefit all. It is a natural extension of herd health and record keeping related to production in which veterinarians are already involved. If veterinarians choose not to coordinate quality assurance programs, someone else will fill this important niche, to the detriment of both the veterinary profession and the cattle industry.

BOX 13-25

Prevention of Physical Defects

Do not use injections behind the slope of the shoulder (never in the hip or leg).
Select subcutaneous and intravenous injections whenever possible.
Use the neck when intramuscular injections are required.
No more than 10 ml/injection site.
Use appropriate sized, metal hub needles for injections.
Change needles every 10 head; immediately change the needle if it becomes bent or burred.
Remove horns.
Avoid side brands.

ANIMAL WELFARE CONSIDERATIONS

The beef cattle breeding industry, at least in the United States, has been the subject of less animal welfare concerns than other segments of the livestock industries, possibly because it most closely approximates the social ethic of animal husbandry, and because most ranchers have genuine regard for their animals (Rollin, 1995). The veterinary profession has made major, although largely unheralded, contributions to animal health (and thus animal welfare) by reducing or eliminating disease effects that otherwise would cause untold animal suffering. Although such considerations are important and often neglected, concerns have been raised about a number of animal welfare issues in the cow-calf sector of the cattle industry. These may be of a

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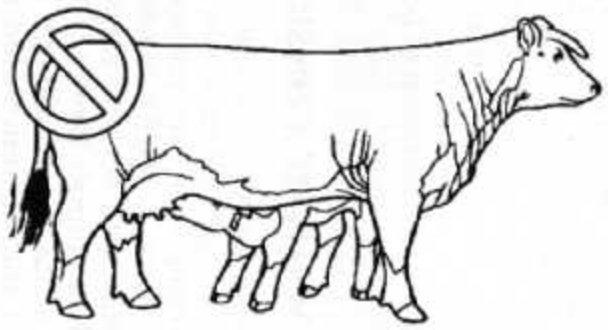
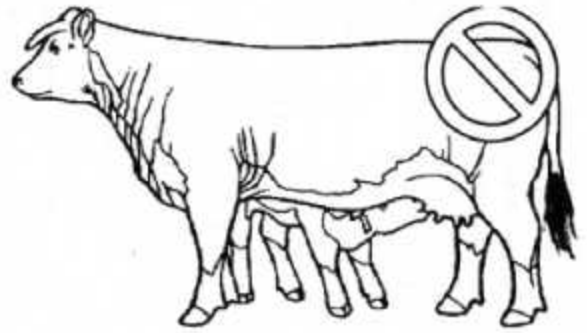
Ranch _____ Cattle group _____ Mgmt Procedures _____

_____





No.	Product	Company	Rx / OTC	Lot No.	Serial No.	Exp. Date	Total Dose	Dose per Site	Route of Admin.	Needle Size	Adverse Cond. (wet, muddy, etc.)	With-drawal Time	Initials

Comments:

_____

_____

Manager/Veterinarian: _____ Date _____

FIG. 13-12 Beef quality assurance record sheet for cow.

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BOX 13-26

Code of Ethics

Provide the food, water, and care necessary to protect the health and well being of their animals.
Provide disease prevention practices to protect the health of the herd, including access to veterinary care.
Provide livestock facilities that allow safe, humane, efficient movement and restraint of animals.
Use humane and legal methods when disposal of animals becomes necessary.
Provide personnel with a working knowledge of proper handling and care techniques.
Make timely observations of all animals to ensure their basic needs are being met.
Provide transportation for cattle that avoids undue stress caused by overcrowding, excess time in transit, or improper handling during loading and unloading.
Do not tolerate persons who willfully mistreat animals.
Keep updated on advancements and changes in the industry and make decisions based on sound production practices and consideration to animal well-being.
Realize that the owner-manager of beef cattle is ethically and financially responsible for providing proper care to his or her livestock and for producing wholesome, quality beef and beef products.

perceptual nature only, and resolvable with good communications, or they may raise valid questions about traditional procedures.

The emergence of questions about traditional procedures has prompted cattle producers to articulate general recommendations for the care and handling of cattle. In Australia, codes of practice have been developed for different industries in a process of consultation by interested parties (Penson, 1998). The Code of Cattle Practice, for example, attempts to meet three general objectives as follows:

1. To promote humane and considerate treatment of cattle and the use of good husbandry practices to improve the welfare of cattle in all types of cattle farming enterprise
2. To provide information concerning their obligations and responsibilities to all people responsible for the care and management of cattle
3. To set an industry standard by defining acceptable cattle management practices

A representative "code of ethics" has been developed by cattlemen in Nebraska (as with a number of cattle organizations), as shown in Box 13-26.

Agriculture Canada has published a "Recommended Code of Practice for the Care and Handling of Food Animals: Beef Cattle" (Hurnik, 1991) that covers a wide spectrum of topics from shelter and housing to commercial transportation, and the Federation of Animal Science Societies in the United States produces a useful compendium that covers welfare considerations for a number of species including beef cattle (Federation of Animal Science Societies, 1999). Proceedings of relevant conferences include those on "Grazing Animal Welfare" (Moore and Chenoweth, 1985) and "Food Animal Well-Being," hosted by the USDA and Purdue University in 1993. Readers interested in this topic might consult relevant sections in the text edited by Temple Grandin (1993) and that written by Bernard Rollin (1995).

Some specific welfare issues have been raised in relation to the cattle breeding industry. These include branding, castration, spaying, weaning, dehorning, cattle handling and transport, EEJ, serving-capacity testing, adverse environmental effects, treatment of cull cows, and surgical preparation of teaser bulls. Veterinarians should be aware of these questions and be prepared to provide informed, objective responses when they are raised. There are good reasons for most procedures in the cattle industry, and those that might appear to be inhumane to those outside the industry can often be justified on good grounds that include sound welfare considerations. However, procedures that cause unnecessary pain or suffering should be scrutinized closely. Those that are unjustifiable should be discarded, and viable alternatives should be investigated for others. A full discussion of all welfare topics deserves its own chapter, or even book; Rollin (1995) presents relevant arguments. This section focuses on several issues of recent concern that relate to topics discussed elsewhere in this chapter.

Bull Electroejaculation

Welfare concerns relating to bull BSE in bulls have mainly focused upon the use of EEJ to obtain semen. The development of effective EEJ first allowed routine testing procedures with unhandled range beef bulls as well as from wild and endangered species. Such animals cannot be collected safely by traditional means, such as with an AV. In bulls, studies have shown that a representative semen sample obtained by EEJ is comparable in most important respects with that obtained with an AV (Singleton, 1970). Not only does EEJ permit range-type bulls to be evaluated, but it allows semen to be collected from bulls whose physical or other impairment rules out AV collection. Despite this, the EEJ process does cause some discomfort to bulls, if not distress, although constant improvement in probe design and machine circuitry have led to a marked reduction of such signs. One study ascertained that bull heart rates were less when an epidural was given before EEJ, although no comparison was made with other activities, either painful or pleasurable (Mosure et al, 1998). In rams, based on relative aversion, EEJ was considered no more aversive than part shearing (Stafford, 1995). Ram blood cortisol levels were shown to be similar for shearing, EEJ, and lateral restraint (Stafford, 1995). Other work has indicated that, although blood cortisol levels were elevated with bull EEJ, these were not as high as those caused by restraint alone, or by per-rectal palpation (Welsh and Johnson, 1981). In addressing this issue, relevant questions might include the following: Does EEJ fall within the category of routine, necessary managerial procedure? If so, does it cause more distress than other routine, necessary procedures? Does it cause unnecessary pain or harm? In other words, do the costs in term of animal distress outweigh the benefits? Here, the debate may be different between those countries or regions that have predominantly range- or pasture-based natural breeding systems (e.g., the Americas and Australasia), and those in which AI predominates, as in Europe where several countries have banned this procedure in unanesthetized animals. Although male fertility is important in both cases, it is usually assessed with unhandled bulls in the former case, compared with bulls that are used to handling and AV collection in the latter. For unhandled bulls, the choice is either to use a method of semen collection that poses minimal danger to both man and beast (e.g., EEJ) or to avoid semen assessment altogether. As discussed previously, the second approach would lead to infertility in breeding herds, adding extra economic burdens to producers and added stress to natural resources. If it is conceded that EEJ represents a

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BOX 13-27

Australian Association of Cattle Veterinarians Guidelines

The service crates used should be designed properly for adequate restraint of previously unhandled females.
Bull groups should be managed so that a number of bulls do not simultaneously compete for a single female.
Significant size disparities between males and females should be avoided, as should be the conduct of tests in which there is uneven terrain or unsound footing.
Females of suitable temperament should be selected where possible. Mild sedation should be a routine option.
Females showing signs of agitation or distress should be replaced expeditiously.
Stimulus females should undergo regular application of lubricant to their vulvas and posterior vaginas.
Females that have been serviced a number of times should be monitored subsequently for untoward sequelae and treated accordingly.

useful, routine managerial tool, then it is still valid to ask whether or not the pain outweighs the gain. Here, although objective studies are lacking, observations indicate that this procedure is no more distressful than other accepted procedures such as restraint, vaccination, or palpation, although the degree of distress is probably influenced by probe design, restraint method, and experience of the operator (Stafford, 1995). Thus bull EEJ may be considered an essential, routine, managerial task that causes no more distress than other tasks in this category. However, it should be conducted as humanely as possible.

Bull Libido–Serving Capacity Testing

The use of restrained nonestrus females as stimuli for bull sex drive testing, a feature of a number of published procedures, has led to understandable concerns for the welfare of the females so utilized. These concerns have led to the development of the guidelines shown in Box 13-27 for the proper conduct of such tests (Anon, 1998).

Consideration should also be shown for the welfare of the bulls being tested. Some appropriate precautions are as follows:

1. Do not congregate groups of bulls in yards or pens any longer than necessary, since such congregation increases the chances of bull injury. This is particularly true for older bulls, but it also applies to mixed age bull groups.
2. Separate any bulls that are showing aggressive behaviors that threaten other animals.
3. Avoid using service crates that have projecting edges or other design features that may injure animals.

Cull Cow Management and Handling

Welfare aspects of cull cow management and marketing have received attention for several reasons. Firstly, cull cows often represent a vulnerable group of animals. Survey data in the United States indicate that a large number of U.S. cull animals have a number of defects in health, quality, or both (Executive Summary, 1994). Indications are that many of these animals are sent to market with little concern for the health and well-being of the animal, or public concerns about food health or quality (Spire, 1997). In addition, these defects were estimated to cause industry-wide losses of $32.34/head.

Problems encountered included animals in which debilitating disease or infirmity was well progressed (obviously unhealthy animals are severely discounted), extensive bruising, injection-site lesions, and poor body condition.

Veterinarians can play an important role in ensuring that the culling process meets welfare as well as production needs. First, they can educate clients of the need to identify potential problems early. This allows timely shipment or intervention. With the latter the decision to intervene medically or surgically as well as product choice and route of administration also influences the marketability of animals that are sold subsequently. Good records of all such interventions and products should be maintained. In a number of cases, the best option may be to maintain the cull animal on an appropriate nutrition program until they are in suitable condition for market. This may also allow time for markets to improve.

Cull cows are often old, sick, injured, or diseased. Welfare codes for injured, sick, and disabled cattle have been developed by different organizations, with the following examples from guidelines produced by Agriculture Canada (Hurnick, 1991):

- Only cattle fit to travel should be considered for transportation, unless special precautions are taken to ensure the animal does not suffer
- An animal that becomes injured, sick, or disabled during transit must be taken to an appropriate place for treatment; special precautions must be taken to minimize its suffering
- An animal that becomes injured, sick, or disabled in transit should be kept separate from other animals

A prominent welfare issue associated with transportation and marketing is that of bruising. Research indicates that presence of horns (tipped or not) as well as class of cattle (bull, steer, cow, calf) are important determinants (Wythes et al, 1985), with temperament also playing a role (Fordyce et al, 1985). Cows were most likely to suffer bruising, as were animals in poor condition or dehydrated. Movement through saleyards, distance traveled, rough handling, and multiple loadings and unloadings also contributed to increased bruising (Hoffman et al, 1998). Many of these determinants have particular significance for cull cows. Practitioners are advised to handle cows with more care than other classes of livestock and to subject them to less handling and "strenuous" schedules (Wythes et al, 1985; Hoffman et al, 1998). These factors all have relevance for cull cow welfare.

VETERINARY RESOURCES

A number of resources are available to assist veterinarians in effectively implementing herd-health and production programs. These resources fall into two general categories: those associated with education and training and those associated with implementation.

Education and Training

Veterinarians seldom have all of the tools necessary to implement herd-health/production programs when they first graduate from veterinary school. This is understandable,

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since the standard veterinary educational process is often overstretched in providing the essential basics upon which the production-oriented veterinarian can later build. This education provides the basis for a majority of veterinarians who provide competent medical and surgical services for companion- and food-animal clients. However, a career in production medicine generally requires training or education beyond basic veterinary education and an emphasis on populations of animals rather than on individuals. Production medicine has many facets, with differing requirements, and preparation for a career in this field varies accordingly. Veterinarians who are successful in this area have arrived at this point through a variety of pathways. In general, however, veterinarians aiming toward a successful cow-calf–oriented, production medicine career are first advised to become knowledgeable concerning the industry, its procedures, terminology, constraints, and applicable production medicine concepts. The development of "marketable skills" (Chenoweth, 1989), such as pregnancy testing or bull evaluation, provides an opportunity to gain access to producers, to gain their confidence, and to use this as a basis to develop more comprehensive programs while acquiring relevant knowledge and skills. On-the-job training with one or more cooperator herds can be invaluable. Enhanced capabilities in reproduction, nutrition, epidemiology, financial management, data handling and analysis, risk analysis, agricultural engineering, personnel management, and communication skills are all highly relevant to such a career. These capabilities may be developed in a number of ways, including formal postveterinary education (such as with an MS or Ph.D.) or continuing education programs. In the latter category programs include the "Beef Cattle Production Management Series," conducted by the Great Plains Veterinary Educational Center, part of the University of Nebraska (Lincoln). This program aims to train veterinarians to use tools to evaluate and monitor production-management strategies and integrate the many factors involved in decision making to optimize productivity and improve financial success for beef cattle producers (Hamilton, 1997). The program is multidisciplinary and interactive, consisting of seven 3-day sessions conducted at the Center over a 12- to 15-month period, with an emphasis on problem solving at whole-farm and industry levels. Topics include financial management, nutrition, preharvest food safety, epidemiology, data handling and analysis, and communication skills. At Colorado State University, the Integrated Livestock Management Program offers a coordinated approach for both continuing education and graduate level training. The University of California-Davis offers a Master's program with a strong epidemiological emphasis in Veterinary Preventive Medicine, whereas the University of Guelph (Ontario), which also has a strong epidemiology program, offers a Doctor of Veterinary Science program. Although this program has a clinical emphasis, it may be tailored toward production medicine interests. In Australia, advanced training in tropical veterinary medicine is available at the James Cook University of North Queensland, while a Master's program in production medicine is offered by the Pastoral Veterinary Center of the University of Queensland. In Victoria, the Mackinnon project at the University of Melbourne offers post-DVM training in production medicine for food- and fiber-producing animals (Caple et al, 1998). Relevant training could also be obtained through less traditional routes, such as with a Master's of Business Administration (MBA). No doubt there are a number of other opportunities for veterinarians to develop expertise relevant to production medicine.

BOX 13-28

Steps to Implement a Production Medicine Program

Establish goals for operation
Establish a herd data base
Identify areas of production inefficiency
Identify areas of financial deficiency
Identify areas for improvement
Establish a plan and timetable
Implement and monitor plan and progress
Document and evaluate outcomes

Implementation

Implementation of effective production medicine programs involves a systematic approach that might include some or all of the steps in Box 13-28.

Although veterinarians often have the training, farm access, and credibility to capably implement such programs, they do not necessarily have expertise in all appropriate areas. In fact, the list of appropriate expertise for all facets of such programs is beyond the resources of most individuals. Fortunately, resources are often available to help in many such areas, including nutrition, finances, and agricultural engineering. Extension personnel, diagnostic laboratories, regulatory agencies, and veterinary colleges all provide a wealth of pertinent information, as do many sites on the World Wide Web.

The formation of teams, or task forces, that combine appropriate expertise for a specific industry problem or sector, has received considerable attention. One such example is that of integrated resource management (IRM), which was conceived by extension specialists in conjunction with the NCBA (formerly NCA) as a national beef educational effort in the United States. Out of this initiative came the guidelines for SPA, as discussed previously in this chapter. Other IRM concepts are expressed in terms of workshops, financial and production analysis programs, development of educational materials such as CD-ROMs, and on-farm problem analysis using multidisciplines. All of these activities benefit from veterinary involvement, particularly on-farm problem solving by teams of expert advisors, such that IRM concepts are now being taught in some U.S. veterinary colleges. Related initiatives include the development of focus teams for different sectors of the animal industry in Missouri, with the beef focus team utilizing veterinary expertise as well as that in areas of economics, forage systems engineering, nutrition, and environmental regulation. In Texas a partnership has been established among veterinarians, extension personnel, producers, and a large pharmaceutical company to help cow-calf producers improve both productivity and profitability through a series of continuing education programs (Wikse et al, 1998). In Australia the development of advisory teams to investigate and solve producers' problems has also met with success (Withers, 1984; Sykes and Stafford, 1984). Such examples illustrate the growing complexity and sophistication of animal agriculture and the need to approach problems from a broad perspective. Today this perspective may include not only whole-farm, or even industry, considerations, but aspects such as international trade, environmental concerns, and animal welfare perceptions (Box 13-28).

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CHAPTER 14

Health and Production Management in Beef Feedlots

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A beef feedlot is a place where young growing cattle are fed a high-energy diet to produce marketable beef at the lowest cost and in the shortest time possible. Depending on the starting body weight and age of the cattle, the period of confinement and feeding varies from 60 days to 12 months.

Beef feedlots have evolved from small family farm lots, in which 25 to 100 head of cattle were finished annually, into large, capital-intensive enterprises that market thousands of finished cattle annually. In the family farm feedlot the calves were born and reared on the home farm, weaned at 6 to 8 months of age, fed a growing ration until they were 1 year of age, and then finished on a high-energy ration, usually grains, until they reached marketable weight at 18 to 24 months of age. Health and production problems were minimal, and expansion of this kind of enterprise was limited only by the capital investment and the desire, knowledge, and labor necessary for expansion.

In North America, expansion of these farm feedlots has been limited when compared with the proliferation of the capital-intensive enterprises that feed and market thousands of cattle annually. Beginning in the 1950s, economic forces led to the development of a large feedlot industry. Feedlots may purchase and own cattle exclusively, custom feed cattle for absentee owners, or a combination of both. In these enterprises cattle are obtained either as weaned calves 6 to 8 months old or as yearlings 12 to 14 months old; they are placed in the feedlot and fed for periods ranging from 60 days to 12 months, depending on initial age and weight. The animals are obtained and transported long distances from many different genetic, nutritional, and geographical backgrounds and are commingled in the feedlot. Net profit in these intensive feedlots depends not only on good animal management and animal health, but also in large part on the purchase and selling prices of the cattle. The cattle are fed primarily on an ad libitum basis, and the aim is to produce a wholesome product for consumers as efficiently and economically as possible with a minimum occurrence of the common diseases that affect feedlot cattle. Feedlot owners have long believed that if cattle are bought right, a profit can be made. However, a number of other factors affect profitability: fed cattle prices, feed conversions, daily gains, interest rates, and even seasonality (Jones and Mintert, 1997). In some cases the occurrence of disease may have a major economic impact on net profit in the feedlot, but in other cases, if the selling price of cattle increases markedly during the finishing period, disease may play only a minor role in net profit. Unexpected fluctuation in the prices of feed and cattle can lead to large financial losses.

In North American feedlots the male castrate (steer) is the predominant animal, but heifers, cull cows, and bulls are also fed for beef production. Young bulls convert feed energy and protein to lean beef more efficiently than do steers (MacNeil et al, 1989; Steen, 1994). Carcasses from bulls slaughtered at traditional weights and ages are leaner than carcasses of contemporary steers. However, lean beef production from young bulls remains an available production system that is currently not exploited. Cattle feeders may be reluctant to feed young bulls in feedlots because of the perceived liabilities and management problems that result from their agonistic behavior. The successful feeding of yearling bulls in the feedlot may depend on the use of management and feeding techniques that reduce the length of the feeding period and the adverse consequences of agonistic behavior (MacNeil et al, 1989).

Energy use in agriculture in general and in beef production in particular has been the topic of much discussion. The added energy inputs, which were substituted for the labor of humans and horses into agriculture, has certainly been a large contributor to the increased production of agriculture (Heitschmidt et al, 1996). Total energy used in the various steps of the beef production system, under conditions of cow-calf production on a range in Colorado with yearling steers fed a high-concentrate diet, is shown in Table 14-1 (Ward, 1980).

Cow-calf production involves support of cows, including their winter feed. Transport of personnel and supplies to the

TABLE 14-1

Distribution of Energy Consumption in Average Beef Production

		Percent
Cow-calf production		21.2
Stocker (180 to 320 kg)		16.0
Feedlot (320 to 500 kg)		62.8
	Total	100.0
ENERGY CONSUMPTION IN THE FEEDLOT		
Feed production		86.4
Feed processing		3.5
Feed operation		10.1
	Total	100.0

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pastures represents the largest single energy input. The feedlot phase represents 60% of the total energy use, of which more than 80% is allocated for feed production. Despite heavy mechanization, feed processing and feedlot operation constitute a small percentage of the total. The fact that so much of the energy input is in the form of feed means that growth promotants that increase feed efficiency make an important contribution to energy conservation. Allocation of energy by system of production tends to favor the feedlot system over higher roughage–based systems because of increases in efficiency. Total energy required per pound (kilogram) of meat produced is reduced by 37% to 40% when increasing amounts of feed energy are obtained from human edible sources (Council for Agricultural Science and Technology, 1999). In addition, significant energy savings in beef production can be obtained by reducing the days on feed for heavy feedlot cattle. This can be achieved by eliminating the additional feeding time for cattle that have reached an optimum endpoint. Ten percent of the total energy for finishing an animal is used during these 2 weeks to produce an additional 2.2 lb (1 kg) of protein along with about 8.8 lb (4 kg) of largely undesirable fat.

The extensive use of hormone implants and feed additives to promote growth and improve feed efficiency has been economical and has had an impact on reducing the costs of feeding high-concentrate grain diets. The major benefactor of reduced input costs has been the consumer.

Because of the high cost of grain in some parts of the world, there has been considerable research activity on a global basis to find inexpensive alternative feeds for all parts of the cattle production cycle. Developments in forage production and quality show promise for decreasing costs associated with growing cattle. Wheat pasture, alfalfa, fescue, and other tame pastures offer great potential for grazing cattle. In addition, grazing crop residue (plant material left in the field after harvest) offers real potential to reduce maintenance costs.

By-product feeding—that is, the feeding of feedstuffs that have been processed for alternative purposes—is a major component of feedlot diets in many parts of the world. Wheat middlings, the by-product of the flour milling industry, corn hominy, potato-processing residue, bakery waste, and other by-products of food-processing industries can replace some of the grain portion as an energy source for growing and finishing beef cattle. In addition, by-products of the ethanol industry, brewing industry, and sweetener industry (e.g., corn gluten feed, steep liquor, barley products) are used extensively in the growing and finishing cattle industry.

Major changes occurred in the beef cattle feedlot industry during the 25 years between 1958 and 1983 (Koch and Algeo, 1983). In the 1960s the commercial and custom cattle-feeding industry in the United States underwent a dramatic shift in numbers, geographical location, and technological handling of cattle and commodities. Large-scale custom feeding operations developed in which the operators of the feedlot did not own the cattle but instead fed and handled them on consignment for absentee owners. Large-scale modern abattoirs were built in the beef-producing areas. Growth promotants came into general use, providing an economic benefit to the consumer. Research into grain processing led to increased efficiency in feed use, and many changes occurred in the marketing and processing of beef cattle.

During this same period there was a major drive in the beef-cattle industry to produce a superior carcass (Berg and Walters, 1983), characterized by a high proportion of muscle, a low proportion of bone, and an optimum level of fatness. The resulting changes included a decrease in fatness at an acceptable slaughter weight and an increase in growth rate accompanied by larger mature sizes. Changes in body form accompanied the changes in growth rate and composition. All of this has led to major changes in the grading systems for beef in North America (Bredenstein and Carpenter, 1983). The use of crossbred cattle selected for growth and leanness has been a major factor in the changes in animal product composition and has implications for animal production systems.

It is clear that the efficiency of beef production has been improved steadily by applying new knowledge of nutrition and breeding (Trenkle and Willham, 1977). Advances in nutrition, management, reproduction, genetics, animal breeding, and meat processing have been significant but not significant enough to make beef cattle production and beef processing routinely profitable. To increase the efficiency of beef production, additional advances must occur in genetics and animal breeding, management, nutrition, reproduction, growth biology, marketing, meat processing, and meat merchandising. The beef industry is fortunate that its primary end product not only is very nutritional but also is enjoyed by consumers. Consumers will continue to demand both highly palatable beef products that are competitively priced with other animal protein sources and composition that leads to optimum nutritional value.

The beef feedlot industry in the United States and Canada developed as a result of the surplus of grain and the demand for beef from the North American public. In Europe, where land and feed are expensive, intensive beef feedlots are rare, and dual-purpose cattle are customary. In most European countries, beef and veal production is a by-product of milk production, and consequently production levels are dependent mainly on changes in dairy cow numbers 1 to 2 years earlier (Allen et al, 1982).

ECONOMICS OF THE FEEDLOT

There are two important economic factors that determine the profitability of a feedlot operation:

1. Cattle increase in weight, and the cost of the gain in weight must be less than the value of the weight. However, this factor is not sufficient in itself, because it is often not possible to make an adequate profit out of a simple gain in weight.
2. The quality of the entire animal is changed so that the entire carcass increases in value per pound (kilogram) of body weight, and this "margin" is the basis of profitability for the feedlot system. The margin varies, because the demand for feedstuffs and available feeder cattle is variable enough that prices for them fluctuate continuously. What makes the system work is the demand for a continuous supply of meat of uniform quality and tenderness at all times of the year.

The principal factor that affects the cost of growth and finishing of cattle in the feedlot is the cost of feed. Other input costs include capital cost of the lot and labor included as a component of yardage costs, interest costs, processing, and veterinary costs (Jones and Mintert, 1997). The longer the animal remains in the lot to reach a specified gain in weight, the less economically efficient the system becomes. Thus there is an incentive to feed out cattle quickly. On the other hand, very heavy feeding may go beyond the point of optimum conversion, and therefore both weight gain per day and feed conversion efficiency must be kept in view as criteria of efficiency. The rate of gain per day increases as the proportion of grain in the diet increases, whereas under normal conditions the efficiency of conversion increases at the same time. Increasing the intake of roughage generally has the opposite effect, and therefore a decision on the optimum proportion of grain and roughage is critical to

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profitability. This decision must also take into account the relative costs of grain and roughage. There are also limitations on the amount of grain that can be fed safely. High-grain diets must be managed correctly to avoid digestive upsets and clinical cases of acidosis.

Rate of gain in body weight and feed conversion efficiency are both strongly inherited, and the purchase of efficient animals can make a considerable contribution to profitability.

Another important factor in determining profitability is disease. The failure to adequately control disease at an economic level can cause complete loss of profitability and the loss of part or all of the asset invested in the cattle. The spectrum of diseases that occur will vary considerably, depending on the management system and the geographical location of the lot. These diseases will be discussed in a later section on the causes of economical loss in the feedlot.

Of great importance in maximizing the profitability of a feedlot is the number of throughputs that can be managed in a year. The capital investment is often such that it is necessary to maintain the lot as close to maximum capacity as possible to spread depreciation and other operating costs, including labor, over as many animals as possible.

EFFECTS OF GENETICS ON BEEF PRODUCTION IN THE FEEDLOT

The increase of the efficiency of beef production systems by genetic methods primarily involves two procedures: selection within breeds to enhance critical characteristics and selection among combinations of breeds to produce individuals that better fit production conditions and resources (Long, 1980). Crossbreeding for beef production has become a generally recommended and accepted practice (Gregory and Cundliff, 1980). The current recommendations for crossbreeding can be explained in terms of heterosis for traits usually considered desirable in terms of profitability. Beef production consists of two phases: the cow herd phase, in which reproduction, or increasing the number of cattle, is of primary importance; and the growth and fattening phase, in which weight increase is of primary importance. The characteristics critical to efficiency during the growth and fattening phase include the postweaning average daily weight gain, yearling weight, postyearling weight gain, feed conversion, and carcass characteristics. Crossbreeding improves each of these characteristics to varying degrees. The effects of management must be considered when assessing the economic impact of crossbreeding (Long, 1980).

Much higher levels of heterosis have been observed in crosses of *Bos indicus* and *Bos taurus* cattle than in crosses of *Bos taurus*. Much of this higher level of heterosis may result from less common gene frequency within *Bos indicus* versus *Bos taurus* cattle. This causes a greater amount of heterosis effect. The crossbreed is a genetic intermediate that may be better adapted than the parental pure breeds, both to the climatic environment and for meeting beef production requirements in moderately intensive beef production systems. A disadvantage of *Bos indicus* cattle and its crosses is one of decreased meat quality as it relates to beef tenderness (O'Connor et al, 1997).

VETERINARY MEDICINE IN THE FEEDLOT

The veterinarian must be a competent gross pathologist, a clinical diagnostician, and an epidemiologist, and he or she must have applied knowledge of feedlot production and nutrition, economics and marketing, and computer-based record keeping.

The role of the veterinarian in the feedlot has changed from the traditional emphasis on the diagnosis and treatment of individual sick animals to that of a professional adviser (Jim and Guichon, 1989; Lechtenberg et al, 1998). Advice on animal health and how it affects animal performance is based on the clinical and pathological examination of animals and on the records of animal health and performance. The details of these procedures are presented later.

Compared with other specialties in veterinary medicine (small animal practice and dairy herd health), feedlot health management has been slower to develop as a recognized specialty with a reliable body of knowledge. This is the result of at least two factors: a lack of knowledge and comfort with the management of feedlots, and practical application of the concepts of population medicine. At the same time, veterinarians have been slow to abandon comfortable areas of large animal practice such as reproductive programs and surgery.

There is a continuing need for the collation of a reliable body of knowledge in feedlot animal health that can be put to use successfully and economically by veterinarians working in feedlots. This body of knowledge should be epidemiologically based and computer generated to maintain animal health at a level that yields optimum feedlot beef cattle performance.

TYPES OF FEEDLOTS

The end product of all feedlots is beef and the resulting by-products of the industry. The major variations among feedlots are the types and quality of cattle that are fed, the feeds used, and the length of the feeding period. A brief description of the characteristics of the common feedlots follows.

North American Feedlots

The primary objective of the North American permanent feedlot is to control the social and nutritional environment of the animals and to produce a wholesome product that meets the needs of the consumer. The types and weights of cattle purchased may vary depending on the market. Every action is conducted in such a way as to achieve the optimum animal and financial advantage.

The cattle and facilities may be totally owned by the owner of the feedlot, who buys and sells the cattle and assumes total responsibility for the management of the production and health of the cattle. In "custom" feedlots, the owner of the cattle makes a contract with the owner of the feedlot, who assumes total responsibility for managing the production and health of the cattle for a predetermined fee. The owner of the feedlot does not participate directly in any profit or loss.

The modern feedlot in North America has become a highly mechanized, well-organized, highly financed enterprise. Capacities range from 1000 to 130,000 head and higher, with at least two throughputs per year. Feed processing and feeding systems are highly mechanized, automated, and computerized, and rations can be changed on short notice by on-site feed mills. Specialized personnel process the feed, pen checkers monitor the animals regularly for illness, and a treatment crew is responsible for treatment of sick animals and the processing of cattle on arrival. Certain pens are allocated for new arrivals, and hospital pens are available for segregation of sick animals. Detailed records are kept of morbidity, mortality, treatments given, and production performance. Detailed financial records of each item of production are kept so that aberrant variations can be examined and corrected if possible (Brennan and Hoffman, 1989; Lechtenberg et al, 1998).

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There must be a variety of options in the manner in which feedlots are operated, depending on availability of cattle and feed; the options may vary in a particular locality from time to time. However, the final stage in any beef feedlot operation is a period of intensive feeding on a carbohydrate-rich diet to finish the cattle with a light cover of fat on the carcass and deposition of fat in the muscle tissue itself (marbling).

The traditional permanent feedlot has a number of options. Cattle are bought at various ages, and the economics of the various situations are different. Young cattle may be bought at 6 months of age, immediately after weaning, when they may weigh 400 to 700 lb (180 to 320 kg); they are either fed intensively until they weigh 1200 lb (550 kg), usually at 14 to 16 months. Alternatively, they may be fed roughage at slightly above maintenance levels through the winter months (stocker phase), then placed on pasture until they are about 14 months old and weigh 750 to 900 lb (340 to 400 kg), when they are put onto heavy grain feeding. In areas where wheat pasture is available, economical gains can be achieved through the fall and winter months.

When older cattle are brought in—usually yearlings weighing 600 to 900 lb (275 to 400 kg) at 12 to 18 months of age—they are normally stepped up to the final finishing rations within 2 to 3 weeks of arrival and may spend from 90 to 150 days on feed. The objective in the feeding strategy program is to achieve a growth rate of 3 to 4 lb/day (1.4 to 1.8 kg/day), which adds 300 to 600 lb (135 to 273 kg) of body weight. In terms of feed the objective is to put on these weights using 5 to 7 lb (2.3 to 3.2 kg) of ration on a dry matter basis per pound of weight gain. Levels of concentrate in the finishing diet will vary from 75% to 90%.

In heavy grain feeding programs, special disease problems are related to abnormal digestion, especially lactic acid indigestion and bloating. Careful feeding management is necessary to avoid losses from these diseases.

The key to managerial success in feedlot feeding is being able to get cattle onto full feed quickly without causing losses from lactic acid indigestion. Details of recommended feeding programs are given later in the section on disease prevention. Because of the pressure to improve the economy of lot feeding, there is a constant search for low-priced, carbohydrate-rich feeds. As a result the use of by-products, particularly corn by-products, in the rations of feedlot cattle has dramatically increased.

Farm Feedlots

Small farm feedlots that feed between 100 and 1000 animals annually still account for a significant part of the feedlot industry in North America. Cow-calf enterprises with between 100 and 300 to 500 cows may retain some steers and heifers and feed them to finish for market directly on the farm. In some cases the owners will purchase between 50 and 300 to 500 feedlot calves from public sales yards and add them to the farm feedlot. The feeds used include cereal grains and corn silage, and mixtures of a variety of roughages depending on availability. The animal health management needs of these farm feedlots are similar to those of larger feedlots, although they are not of the same magnitude.

Backgrounding for the Feedlot

Backgrounding is a feeding enterprise in which recently weaned calves are grown to yearling feeder cattle weight, usually in a smaller feedlot. The principal objective is to prepare cattle to adjust to a high-energy finishing ration in a feedlot with minimal health problems. This is achieved by feeding the calves a growing diet that yields rapid, efficient body weight gains without fattening. Maximum use is made of roughage-type diets. The spectrum of diseases that occur in backgrounding enterprises during the first 45 days after arrival of the calves depends on whether the calves originate from one or many different sources and on whether they have been preconditioned or immunized before arrival.

Beef Feedlots in Australia

Beef feedlotting in Australia has begun to develop and resemble that of North America (Moore, 1990). Capacity growth since the late 1960s has been generated primarily because of demand for beef from Japan and, more recently, Korea, from major supermarket stores domestically, and from the hotel and restaurant trade. Until relatively recently, the scale of operations in Australia has been smaller than that in North America, but many of the principles have been the same. These include facilities located in grain-growing areas; preference for low rainfall areas; facilities located within a reasonable distance of abattoirs; and good water as an essential element. The feedlot industry developed as a way to ensure consistent quality of beef for domestic use, but the dependency on pasture-fattened cattle was a problem because of the vagaries of Australian weather patterns, particularly drought; the ready availability of grain; and the ability to meet market demands. Feedlot capacities have grown from a range of 1000 to 8000 head to greater capacities of 30,000 to 60,000 today. The current capacity for Australian feedlots is somewhat greater than 750,000 head of cattle.

"Barley-Beef" Units in the United Kingdom

In the British system cattle are introduced to the units when they are 3 months old and weigh 200 to 220 lb (90 to 100 kg). The objective is to market them at 800 to 900 lb (360 to 400 kg) before they are 12 months old. The capitalization per place in the unit is very small. Because the units are relatively small and house relatively few animals (about 50 to 100 head), little money is spent on sophisticated machinery, milling, or feeding out. Feed is provided by private feed supply companies, which have grown enormously in the United Kingdom since the 1960s. They provide custom-mixed rations, and therefore the feed is a much greater expense than in the United States. The other noticeable difference between the barley-beef and the American "permanent" feedlots is the need in the latter to push animals through an intensive feeding period quickly to utilize highly capitalized cattle space to the fullest. Therefore in these lots there is an average of 2.5 throughputs, whereas in a barley-beef unit, where the pressure of capitalization is not nearly as great, one throughput per year is the average.

A similar system is common throughout eastern and western Europe and in Japan. The number of animals in an individual unit is usually quite small, and the intensity of the feeding program is usually inversely proportional to the number. Male castrates of the local indigenous, dual-purpose breeds are used and are allowed to grow as heavy as 1500 lb (680 kg) on very heavy grain rations, supplemented with a great variety of additional growth stimulants, including beer. Particular emphasis is placed on maximizing the amount of lean meat in the carcass. The

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animals are maintained indoors in small groups for the feeding period, with manure and urine disposed of through a slatted floor or by way of a deep litter system (Allen et al, 1982).

OBJECTIVES OF A HEALTH MANAGEMENT AND PRODUCTION PROGRAM IN THE FEEDLOT

The general objectives of a planned animal health and production program in a feedlot include the following (Church, 1980):

1. Rapid growth rate, minimum of fat at an acceptable slaughter weight, and moderate size at maturity. This is achieved by purchasing cattle with the genetic potential for rapid growth and leanness.
2. Maximization of feed conversion efficiency through the use of growth promotants, formulation of economical rations, effective feeding techniques, effective parasite control, and culling of animals with chronic diseases that are refractory to treatment.
3. Reduction in morbidity, mortality, and culling rates. This requires the purchase of cattle in good health by cattle buyers who know what they are buying. It also requires an effective processing and introductory system that minimizes the incidence of disease as well as animal attendants who can detect and treat clinically affected animals in the early stages of disease. In most instances it requires a reliable record-keeping system using a computer that provides useful information on a daily basis and a simple protocol for the clinical management of sick cattle.
4. Optimization of expenditures for biologicals and antimicrobials used for the control and treatment of disease. This can be done by avoiding unnecessary use of vaccines, anthelmintics, and prophylactic antimicrobials and by treating sick animals as early as possible with the most cost-effective drugs. Long-acting antimicrobials may be used when the morbidity rate is increasing in a new pen of cattle. Treatment response and relapse rate should be monitored and changes made in treatment protocol while avoiding unnecessary treatment and educating animal attendants on the proper use of vaccines and drugs used in the feedlot. In refractory cases, treatment should be discontinued and the animals culled.
5. Maintenance and improvement of employee motivation to provide good animal management and early detection and treatment of sick animals. Animal attendants must be made to feel that they are part of an important team providing animal health care. Such care should be evaluated regularly and the results shared with the attendants; education and communication are vital.
6. A profit commensurate with other investment opportunities. The veterinarian must be aware of the degree of risk aversion in the client.
7. The production of wholesome beef free of chemical residues. This requires reliable individual animal identification, reliable record keeping and cross-referencing before shipment, limited extra-label drug use, and use of drugs with a short withdrawal period on animals near slaughter weight.
8. Because of the large number of animals in a feedlot, a well-operated program with a good record system allows the veterinarian to conduct clinical research on a variety of drugs, particularly antimicrobials and vaccines. Manufacturers of drugs and vaccines view the feedlot as an excellent opportunity and facility in which to conduct clinical research on new products, which is needed for licensure for sale.

STANDARDS FOR HEALTH AND PRODUCTION PERFORMANCE IN THE FEEDLOT

The major factors that influence profit or loss in the feedlot are the price of the purchased cattle, the total cost per unit of body weight gain, and the selling price of finished cattle. There are fluctuations in the costs of feed, which may affect net profit, but major fluctuations in the costs of feeder cattle and the selling price of finished cattle lead to major changes in profit and loss. The individual feedlot operator has no direct control over the price of cattle, and net profit depends on a gross margin that is large enough to offset costs. A decrease in the selling price of cattle can lead to major economic losses; in these conditions, even the very best health and management program cannot lead to a profit, but it can reduce the magnitude of the losses. Conversely, a marked increase in the selling price of cattle usually causes large increases in net profit in spite of an unusually high incidence of disease and mortality in a particular group of cattle. In such cases, disease appears to be insignificant. In fact, in most well-managed feedlots, the waste resulting from disease appears to be relatively small compared with that from other causes. Some of the factors that affect the occurrence of disease and profit are presented in the discussion on the epidemiology of diseases of feedlot cattle. These factors are generally well known to feedlot managers. As a consequence the veterinarian serves as an advisor on the treatment and control of disease, with feedlot-specific advice and implementation. Because management, nutrition, environment, and economics have a close interrelationship with disease, the veterinary consultant to a feedlot must be familiar with each of these disciplines. If veterinarians become involved to a large degree, they may find themselves fitted for the role of manager. This has actually happened in some of the very large feedlots. The most important factor governing the efficiency and success of a feedlot herd health program is the veterinarian's depth of knowledge regarding the managerial factors that form the basis for good cattle health.

Other factors that affect the herd health service include not only the efficiency of the feedlot employees, but also the degree to which they can be motivated by management and the veterinarian. Reliable identification of animals as groups and accurate identification when they are treated—preferably by ear tag—are important. Keeping the cattle together as groups so that their subsequent performance can be traced back to their origin and to their handling during the conditioning period is also important. Proper hospital yards and chutes are needed to permit adequate handling for prophylactic and therapeutic procedures.

Production and Disease Targets in the Feedlot

There is only a limited amount of published, documented information available on the standards of health and performance that should be expected and aimed for in a well-managed commercial beef feedlot. Most feedlots record the details for their cattle on a group or pen basis. These data (pen closeouts) usually include the total weight and costs of cattle going into the pen, the total amount and costs of the feed consumed, the total number of animals (live and dead), the total costs of prophylaxis and treatment, and the total weight and selling price of cattle leaving the pen for market. From these records it is possible to assess the health and production performance. The standards for health and performance and the definitions of morbidity and mortality rates that

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are set out below are guidelines only; these will have to be modified according to the prevailing conditions in each feedlot.

Assessment of General Efficiency

Average daily gain

= (Total weight gained by group (kg)/Number of cattle)/Days on feed

= Not less than 1.2 kg/Day (2.7 lb/day)

Efficiency of feed conversion

= Total feed to group (kg)/Body weight gained by group (kg)

= <7.0

Costs per kilogram of body weight gain are variable, but in the United States they vary from $1.00 ($0.45/lb) to over $1.45 ($0.65/lb) of gain.

Definition and Assessment of Disease Statistics

Case Definition. A review of the literature regarding the methods by which the feedlot industry calculates and reports the occurrence of disease reveals that case definitions are often poorly defined and mostly are based on chemotherapeutic treatment as a criterion. If the animal was identified as being ill and was treated, it was included as a case for calculation of the morbidity rate (Kelly and Janzen, 1986). Thus "treatment" was used as a case definition, and the morbidity rates calculated could be called "treatment rates." Case definitions should always be stated clearly (Kelly and Janzen 1989; Perino and Apley, 1998). However, even though a case definition may be stated clearly, it may not be diagnostic. For example, a case definition for undifferentiated bovine respiratory disease in feedlot cattle may be any animal that appears depressed, has an increased respiratory rate, is removed from the pen, and, on cursory clinical examination, has no evidence of nonrespiratory disease and a body temperature of more than 40° C (104° F) and, is treated with an antimicrobial. Thus it will become part of the morbidity statistic, but it should really be part of the treatment rate. This case definition is not diagnostic, and one or more signs and symptoms may be used as treatment criteria. This means that a depressed animal may be counted as a case the same as an animal that exhibits all of the signs and symptoms. While this definition is clear enough and may be used for comparison from one day to the next, comparisons between feedlots using these criteria may have some agreement but should not be assumed to be exactly alike.

Morbidity and Mortality Rates

There is considerable misuse of morbidity and mortality statistics in North American feedlots (Kelly and Janzen, 1986). The simplest way is to calculate the incidence (cumulative) rate of morbidity in a group of animals. This is done by counting the animals that develop an illness over a period of time (cases) and dividing this number by the total number of animals in the group at the start of the time period. If the population at risk changes, an average may be used for the denominator. The cumulative incidence measures the chance of a randomly selected animal contracting disease during a specific period. Alternatively, the incidence rate is calculated as the number of new cases during a certain period divided by the sum of the time units at risk. The result is a measure of the rate at which the group became ill (e.g., the number of animals sick/animal-week at risk) (Noordhuizen et al, 1997).

The mortality incidence rate is similar, but deaths are counted as cases. The population at risk should be measured precisely, and only those animals that are biologically capable of suffering the disease should be included in the denominator. Because of problems with relapses, when an animal becomes ill with disease, it is conventionally considered to be no longer at risk. The period of observation must be either stated or incorporated into the rate units as above. The principle of using the precise sum of animal-time at risk can be used to any degree of precision (e.g., daily tally intervals instead of weekly) (Kelly and Janzen, 1989). The method is of special relevance to veterinary epidemiology, because large changes in population are common in farm animal situations, and precise records of the changes are often available because of the importance of head counts in agriculture.

There are wide variations in the record-keeping systems used by different feedlots. Most custom feedlots use their records primarily for accounting rather than to evaluate disease. The following definitions can be used to record disease on a monthly basis:

Disease Incident Rate. This incidence describes the number of new cases in a population over a specified period: (number of new clinical disease cases during the month/the number of animals at risk of developing disease during the month) × 100. For example, cattle are at the greatest risk for developing respiratory disease during the first 3 to 4 weeks after arrival, thus cattle received during the month of interest would be included in the denominator. The consultant is interested in the yearly cumulative morbidity rate, and this rate can be found by adding each month's cumulative incidence over a year's time. Alternatively, the total number of pulls (years' time) divided by the total number of received cattle for the year also gives this number. In addition, it is usually of value to know the disease incidence rate by pen.

Death Rate. Death rate can be expressed through this equation:

(Number of animals that died during the month / Average number of animals on feed during the month) × 100

Culling Rate. This is the percentage of animals culled because of chronic illness or inferior performance before the fattening period was completed. It will usually be approximately the same as the annual mortality rate. Culling rate can be expressed through this equation:

(Number of animals culled during the month / Average number of animals on feed during the month) × 100 (Frank et al, 1988)

The system should allow the development of a validated baseline of animal health data for feedlots.

The peak incidence of disease in feedlots in North America occurs soon after the calves arrive in the feedlot. Between 15% and 45% of incoming calves require treatment, and from 1% to 5% die (Kelly and Janzen, 1986). In yearling cattle these numbers will range from 5% to 11%, and death loss will be from 0.5% to 1% (Edwards, 1996).

Annual Population Mortality Rate. The annual population mortality rate is the percentage of the entire population in the feedlot that died during the year. A common standard is 1% or less, with a feasible target of 0.5%. Mortality rates less than this in the feedlot are uncommon because high-energy diets contribute to digestive disturbances and losses, but the rates are accepted as a trade-off for improved performance. Some feedlots report losses of 3% to 4% annually. However, the losses depend primarily on the age and kind of cattle that are purchased and fed. Annual population mortality rates may reach 5% when feeder calves 6 to 8 months old and weighing an average of 500 lb (225 kg) are placed in the feedlot. The population mortality rate for yearling cattle placed in the feedlot and weighing an average of 800 lb (375 kg) is as low as 1%.

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Relapse Rates. The total number of animals that became ill after one or more courses of treatment and the number of times they relapsed should be calculated separately. The relapse rate varies from 5% to 50% but will often be 15% to 20%.

Epidemic Curves. A graph showing the changes in morbidity or mortality rate with time is called an epidemic curve. It displays the dynamics of disease activity in a population and provides a basic epidemiological description (Kelly and Janzen, 1986). The regular occurrence of a disease peak soon after cattle arrive at a feedlot suggests a point source factor, such as stress induced by transportation, feed or water deprivation, the effects of mixing, and fatigue. This is in contrast to a propagated epidemic associated with a contagious disease in which new cases are spread out over a much longer period.

Health and Disease Costs. These are the total costs of health and disease, including the value of dead animals and the costs of prophylaxis and treatment. The total health and disease costs are expressed as a percentage of the total costs per unit of body weight gain per day.

CAUSES OF ECONOMIC LOSS IN THE FEEDLOT

The causes of economic loss in the feedlot vary considerably. The broad factors that influence optimum production and cause economic loss when unsatisfactory include those found in Box 14-1.

The veterinarian will have more impact on health management and disease losses in the feedlot than other areas; therefore this area deserves the most discussion. A thorough understanding of the impact of disease on animal performance and economic loss is essential in order to make cost-effective recommendations to feedlot managers. In 1968, Pierson said, "The hidden loss (due to shipping fever) sometimes exceeds the calculable loss. The hidden loss refers to the chronic poor doers that fail to gain and take much longer to grow to marketable size" (Pierson, 1968). This is still true today. The cost of death loss, chronic cattle marketed prematurely at a discount, and treatment costs are obvious and easy to calculate. Hidden costs, such as reduced performance and lower carcass quality, are often overlooked.

Mortality is an important economic loss in feedlots. Mortality rates can be expressed in two ways: as a percentage of monthly inventory (occupancy) and as a percentage of cattle received. The latter figure is calculated at "close-out," or when the cattle are sold. Calculating the mortality rate each month as a percentage of average inventory allows timely monitoring of trends in mortality. When the monthly mortality rate increases, management adjustments can be made more quickly than when mortality is monitored only at the end of the feeding period, or at "close-out." Mortality expressed as a percentage of inventory is lowest during April, May, and June and highest in November and December. On average, 0.268% of cattle die each month in feedyards; in other words, an average of 27 out of each 10,000 on feed die each month. Most death loss is caused by respiratory disorders and ranges from 0.072% in April to 0.234% of inventory in November. Digestive death losses are highest in November, December, and January, and average 0.061% of monthly inventory. Miscellaneous, or "other," death losses average 0.078% of monthly inventory (Vogel and Parrott, 1994).

The death rate for Holstein feeder steers is higher than beef breeds of cattle. In one report, the monthly mortality rate for Holstein steers averaged 0.419% of inventory compared with an average of 0.268% for beef cattle. A higher proportion of deaths in Holstein feedlot cattle, compared with beef cattle, is due to digestive disorders.

When calculated at "close-out," annual population mortality in well-managed feedlots feeding mostly low-risk cattle ranges from 0.57% to slightly over 1.0% of cattle received (Edwards, 1996). Higher rates are frequently seen (Kelly and Janzen, 1986). Age, size, source of cattle, previous management, and amount of commingling have a great influence on the health problems and the death rate that cattle will experience at the feedlot. About 60% of the deaths occur after cattle have been on feed greater than 45 days. Whereas deaths early in the feeding period are caused primarily by respiratory diseases, those occurring after 45 days on feed are more likely caused by digestive disorders (Edwards, 1996). Mortality rates in smaller feedyards are higher than in large (40,000+) feedyards (Vogel and Parrott, 1994). The reason for this is unknown but is possibly related to type of cattle received (low versus high risk), average number in each group received, labor availability, and location of smaller yards as compared with large feedlots.

Treatment costs are another source of economic loss. Factors influencing the average cost include the morbidity rate, retreatment rate, cost of the drug(s), combination versus

BOX 14-1

Causes of Economic Loss

MARKETS
The cost of cattle and the selling price have the most dramatic effect on the profit or loss resulting from feeding cattle.

NUTRITION
The quality and adequacy of the feeds and feeding systems used have a major impact on growth rate and feed efficiency.

TYPES OF CATTLE FED
Prior nutrition, genetic background, weight, age, and sex of the animals fed influence growth rate, feed efficiency, and carcass quality.

ENVIRONMENTAL EFFECTS
Because feedlot cattle are usually kept in confinement, often with a high stocking density, the effects of environment may interfere with optimum production. Weather impact on performance is greatest during a very cold, wet winter.

MANAGEMENT EXPERTISE
As in any livestock enterprise, the level of management is important. Most of the success of a herd health program depends on the people feeding the cattle, early identification and treatment of sick cattle, and accurate record keeping of daily activities. In large, modern feedlots, management of personnel becomes one of the highest priorities.

DISEASE
Disease may cause economic loss through mortality, treatment costs, or effects on productivity. The impact of clinical and subclinical disease on productive efficiency and economic returns may be greater than the losses associated with mortality.

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single antimicrobial therapy, whether or not adjunct therapy is used, labor, and feedlot markup on the products used. Many feedlots also charge for a chute fee for treating the cattle. Treatment costs are frequently $21 to $23 (U.S. dollars)/animal treated. The morbidity rate has the strongest influence on the average treatment cost for all cattle in the pen. When metaphylaxis is used to manage bovine respiratory tract disease (BRD), it must be added to the total medical cost for the pen.

Respiratory disease has a dramatic effect on the performance of feedlot calves. The reduced daily gain, and subsequent lower market weight, are not obvious to the observer but rather must be measured. Many studies have reported an association between BRD and losses in daily gain. Unfortunately, less is known about the impact of disease on feed efficiency because of the impracticality of measuring it in most field trials. Loss of daily gain after respiratory disease is greatest in the 28- to 30-day receiving period. These differences tend to narrow as days-on-feed increase, but treated calves seldom achieve daily gains of penmates that were not sick. During the first 28 to 30 days on feed, calves with clinical BRD will gain from 0.30 to 0.50 lb (0.14 to 0.23 kg)/day less than penmates that remain healthy (Bateman et al, 1990; Van Donkersgoed et al, 1993; Smith, 1997). At "closeout," differences in gain range from 0.14 to 0.56 lb/day (0.06 to 0.25 kg/day) (Bateman et al, 1990; Texas A&M Ranch to Rail Summaries, 1992-1999).

When cattle relapse with BRD and require a second or third course of therapy, the impact of disease on daily gain is much more significant than the initial episode. At 90 days on feed, a Canadian feedlot study (Morck et al, 1993) showed that cattle sick and treated for BRD once gained 0.39 lb (0.18 kg)/day less than healthy penmates, whereas those that had relapsed gained 0.73 lb (0.33 kg)/day less. Other studies have shown similar effects (Van Donkersgoed et al, 1993). The loss of daily gain associated with BRD results in less saleable weight at the end of the feed period. The economic loss is significant and is magnified if there is an accompanying loss of feed efficiency.

Cattle that are sick and treated return $49.58 to $118 (U.S. dollars) less than cattle that remain healthy throughout the feeding period. The losses include medical costs, reduced performance, increased death loss and culling rate, and reduced carcass quality grade. Based on arrival weight into the feedlot, cattle that become sick are worth from $8.65 to $19 (U.S. dollars) per hundredweight less than cattle that remain healthy (Texas A&M Ranch to Rail Summaries, 1992-1999).

Buying "bargain cattle," such as bulls instead of steers, heifers of unknown pregnancy status, or cattle that have been severely malnourished for an extended period, can cause further economic loss to the cattle owner. These higher risk and often poor performing cattle may provide a good economic return if sufficient purchase discounts are applied. The veterinarian must be able to provide science-based advice on the true value of higher risk cattle. Management of bulls and pregnant heifers is discussed elsewhere in this chapter.

EPIDEMIOLOGY OF DISEASES IN FEEDLOT CATTLE

In its broadest terms a study of the epidemiology of diseases of feedlot cattle would include a description of disease statistics (e.g., morbidity, case fatality, and population mortality rates); the prevalence of the major diseases; the age and seasonal incidence of the economically important diseases; and the epidemiological determinants such as the characteristics of the host, the environment, and the causative agent leading to subclinical or clinical disease. The economic losses associated with feedlot disease include losses from deaths, costs of treatment of animals with clinical disease, potential decrease in carcass of quality grade, and losses from suboptimum performance resulting from both clinical and subclinical disease.

Only a small amount of documented information is available on the epidemiology of feedlot diseases. More knowledge is needed regarding the frequency, epidemiological determinants, and economics of feedlot disease in order to develop animal health management programs that are geared toward the most economically important diseases.

The morbidity rate, case fatality rate, and population mortality rate associated with disease in feedlot cattle vary among feedlots and depend on several factors. Mortality rates are higher in beef calves 6 to 8 months old (2% to 4%) than in yearling cattle (0.5% to 1%). Seventy percent of the morbidity occurs within the first 45 days in the feed lot, whereas only 40% of deaths occur during that same period (Edwards, 1996).

A graph illustrating the changes in morbidity or mortality rate with time is called an epidemic curve (Fig. 14-1). Such a curve displays the dynamics of disease activity in a population and provides a basic epidemiological description. This information is valuable in a feedlot because it allows the veterinarian to formulate control and treatment strategies for some economically important diseases (e.g., respiratory disease). For example, it was thought for many years that shipping fever occurred in feedlot cattle 7 to 14 days after arrival. This was generally true if the affected cattle were shipped directly from the ranch to the feedlot. However, with auction market-derived calves, the epidemic curve for shipping fever shifts left, and the peak occurrence of respiratory disease is much earlier, as early as 4 to 6 days (Fig. 14-2). This suggests that auction-market calves are in the incubation stages of the disease when they arrive in the feedlot because they have been subjected to weaning, transportation, mixing, and feed and water deprivation, in contrast to calves received directly from the ranch that require several days to become ill. When antimicrobial metaphylaxis is used at arrival processing, peak occurrence of clinical respiratory disease in high-risk calves shifts to the right, usually to between 10 and 15 days after arrival (McClary and Vogel, 1999).

The most economically important diseases of feedlot cattle are infectious diseases and diseases associated with intensive feeding of high-energy diets. There are several epidemiological determinants that are usually associated with diseases of feedlot cattle. The animals are usually young (7 to 15 months old) and often have originated from several different sources and thus have unequal acquired resistance to infectious disease, especially respiratory disease. Respiratory disease accounts for 75% of illnesses and 45% to 55% of the population mortality in large feedlots (Edwards, 1996).

The incidence of fatal fibrinous pneumonia is strongly associated with the number of calves per farm on each truckload arriving at the feedlot. This is commonly referred to as commingling or pretransit mixing (Alexander et al, 1989; Ribble et al, 1995b). A high percentage of calves in North America are produced on smaller farms and ranches. When taken to auction markets, calves are sorted by gender, weight, type, and quality before being sold. This further increases the amount of commingling necessary in order to assemble truckload lots of uniform calves.

Season of year is correlated with respiratory morbidity and mortality rates. The highest occurrence of fatal fibrinous pneumonia is in November and December. During the fall season there is also an increase in the number of calves at

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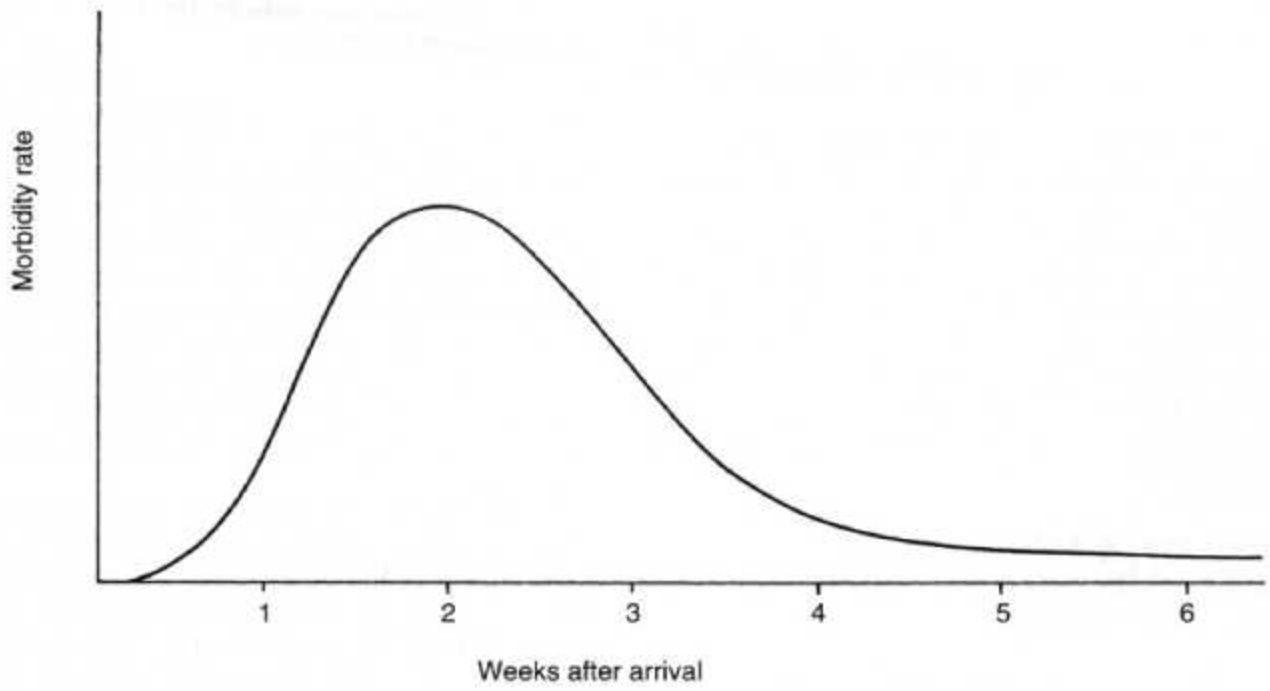

FIG. 14-1 Epidemic curve.

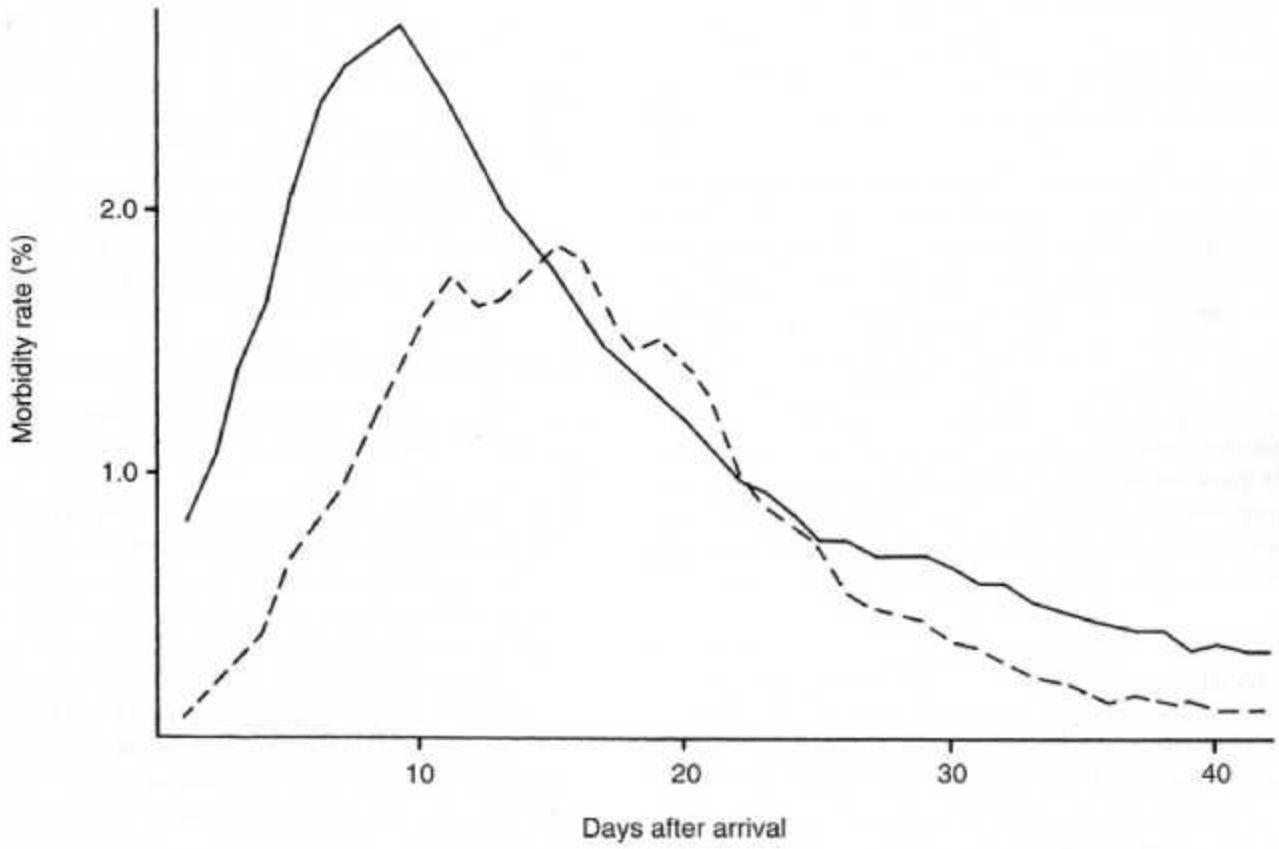

FIG. 14-2 Summary of epidemic curves for 74 groups of auction mart–derived calves (solid lines) and 23 groups of ranch-derived calves (dashed lines). (From Kelly AP, Janzen ED: *Can Vet J* 27:496-500, 1986.)

the auction markets and feedlot receipt of calves' peaks. During this period, feedlot hospitals become crowded and acute cases of respiratory disease are exposed to chronic cases (Ribble et al, 1995a; Vogel and Parrott, 1994).

The incidence of respiratory disease is higher in auction-origin cattle than in ranch source cattle (Wilson et al, 1985). This difference is magnified in the fall of the year when a greater proportion of calves enters the feedlot. The incidence of respiratory disease is higher in steers than in heifers. Heifers that are pregnancy checked are at greater risk of respiratory disease than those not palpated (Alexander et al, 1989). The reason for this is unclear; perhaps the stress of handling and palpation increases susceptibility to respiratory disease, or, more likely, feedlots are more likely to pregnancy-check groups of heifers that are at higher risk of developing respiratory disease.

Other minor diseases of the respiratory tract that occur in feedlot cattle include atypical interstitial pneumonia in yearling cattle (Jensen et al, 1976a), bronchiectasis in yearling cattle (Jensen et al, 1976b), brisket disease in yearling cattle

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that had previously grazed on mountain ranges (Jensen et al, 1976c), embolic pulmonary aneurysms in yearling cattle (Jensen et al, 1976d), diphtheria, and tracheal edema, or "honkers."

Bulling among steers, an abnormal behavioral trait, is a common health and economic problem in feedlot operations. Riders simulate males, and bullers simulate females. Bullers sexually attract the riders, which repeatedly mount and physically injure the bullers. Although this behavior may continue until the bullers become exhausted, collapse, and die, the main economic loss results from physical injury, stress to both buller and rider, and the necessity of early isolation of the affected animals. The prevalence of bullers generally averages 2% to 3% of a feedlot population (Taylor et al, 1997; Edwards, 1995).

COMPONENTS OF A HEALTH MANAGEMENT AND PRODUCTION PROGRAM IN A FEEDLOT

The continued profitable success of a modern feedlot is dependent on the right combination of good management, a favorable economic climate, and relative freedom from unfortunate occurrences such as epidemics of disease or unexpected increases in the costs of inputs (e.g., feed) or decreases in the price received for the final product. Success is heavily dependent on the cattle buyer, the animal attendants, the nutritional consultant, the veterinarian, and the manager of the feedlot, each assuming his or her individual responsibilities and doing the best work possible. In recent years, feedlot veterinary medicine has become a specialty discipline.

Veterinary medicine has been slow to meet the challenge of the feedlot industry. One major reason has been its preoccupation with the diagnosis and treatment of individual sick animals. As feedlots became larger and more sophisticated, it became obvious that knowledgeable animal attendants could successfully and economically diagnose and treat the common diseases of feedlot cattle. Veterinarians were thus used less routinely and were called only when alarming epidemics occurred that did not respond to the usual treatment procedures or in which the feedlot personnel could not make a diagnosis. This has changed, and more feedlots are recognizing the value of constant surveillance by a veterinarian who has specialized in feedlot veterinary medicine.

The successful feedlot veterinarian has a broad concept of disease in the feedlot and does not restrict the definition simply to sick animals. The concept of disease should include all of the identifiable factors that cause suboptimum performance: inadequacies in feeds and feeding systems, the purchase of undesirable types of cattle, and clinical and subclinical disease. The overwhelming majority of the veterinarian's continuing education efforts must be directed toward topics that directly benefit feedlot clients.

Relationship Between Veterinarian and Feedlot Personnel

The respective roles of managers, animal attendants, and the veterinarian must be understood, agreed on, and respected by each party.

Responsibilities of the Feedlot Manager and Animal Health Technician

The responsibility of the feedlot manager is to coordinate the animal health and production activities of the feedlot, using advice obtained from the veterinarian, the nutritional consultant, and any others deemed necessary. The manager must supervise animal health personnel, whose major responsibilities include the identification and treatment of sick animals and the processing of new arrivals.

Close surveillance of all animals in the lot must be maintained once daily (or, in recently introduced animals, twice daily) to detect illness in the earliest stage possible, when therapy is more likely to be successful. Without efficiency in this activity, the remainder of the program is largely pointless. The people who work all day in the feedlot know the cattle and are good livestock personnel. They become very efficient at identifying sick animals. The consulting feedlot veterinarian must remain as good as or better at disease detection than the crew he or she is responsible for training.

Segregation and treatment of sick animals are necessary. The number of diseases likely to be seen in any one feedlot is relatively small, and many of them can be identified easily by a watchful livestock attendant, especially if he or she has been trained properly by the veterinarian. The manager must stay alert for an unusual increase in the incidence or manifestation of a disease.

Managers must supervise the feeding procedures to be used throughout the feeding cycle, especially during the 3-week induction period—a period directed at preventing disease—after the cattle come into the lot. The manager is also responsible for supervising the buying and selling of the cattle and the purchase and processing of feeds and other necessary supplies. Most important, the manager must communicate effectively with the animal health personnel, the veterinarian, and any other consultants. Effective communication is essential to solving problems.

The design of the data collection system and the recording of all health and production performance data are the combined responsibilities of the animal health personnel, the feedlot manager, and the consulting veterinarian.

Responsibilities of the Consulting Veterinarian

The veterinarian is responsible for maintaining optimum animal health through the following activities (Janzen, 1990i):

1. Makes regularly scheduled visits to the feedlot, is punctual, and stays as long as necessary for adequate consultation. The frequency of visits depends on the size of the feedlot, the time of year, the expertise of the feedlot personnel, whether animals have recently arrived, and the degree to which the veterinarian is contractually responsible for the total animal health program.
2. Is available for emergency visits to the feedlot when disease epidemics occur unexpectedly.
3. Performs necropsies during the visit and trains feedlot personnel to do necropsies at other times.
4. Examines sick animals with the treatment crew to ensure that reasonably accurate diagnoses are being made and rational therapy is being given according to the previously provided treatment protocol (Janzen, 1990d).
5. Regularly examines, analyzes, and interprets animal health and production data and periodically makes recommendations in a written report. The effectiveness of detection of sick animals, based on response and relapse rates and case fatality rates, should be determined, and the effectiveness of the processing program for new arrivals, which includes the vaccines used and the medications given, should be examined and analyzed regularly. The veterinarian is responsible for selecting and prescribing all drugs used in the lot, giving specific advice about the use of drugs, and establishing a drug residue avoidance program in the lot.

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6. Discusses overall animal health and production performance with the feedlot manager and other consultants. He or she coordinates the advice of other specialists, sets animal health and production goals, and monitors achievement.
7. Performs benchmarking with other operations. Produces a monthly report that compares processing costs, treatment costs, and death loss by arrival weight and days on feed for clients in the consultants practice (Miles, 1998).
8. Takes an interest in all aspects of the feedlot operation and makes an effort to be aware of new developments in the feedlot industry (Janzen, 1990c,e,g).

Involvement of the Local Veterinarian

In some cases the veterinarian providing consulting services to a feedlot may live a long distance away. When the consulting veterinarian is not readily available, the local practitioner can serve as a valuable resource for the feedlot. Serving as part of the feedlot's health care team, the local veterinarian can make significant contributions to the animal health program. Advantages to involving the local veterinarian include the following (Schwenka, 1998):

1. Availability on a day-to-day basis
   - Focus on the individual animal
   - Help troubleshoot any problems that arise immediately
   - Use consultant's suggestions and provide follow-up
2. Diagnostics
   - Perform necropsies or assist crew with necropsies as the need arises
   - Collect and prepare tissue for proper diagnostic evaluation
   - Advise as to the proper diagnostic test and laboratory work for various problems
3. Processing
   - Assist with developing a processing program that fits the regional area
   - Provide training for the processing crew
   - Provide a processing crew on a contractual basis
4. Treatment program
   - Assist with developing a treatment program
   - Provide follow-up for the treatment program
   - Provide day-to-day monitoring and training for the crew
5. Drug sales
   - Have opportunity to supply drugs
   - Write prescriptions or provide prescription drugs
6. Pregnancy checking

Adversarial relationships between the consulting veterinarian and the local veterinarian must be avoided. The team approach to providing veterinary services is beneficial to all parties involved.

Implementation of a Feedlot Medicine Program

It is a major challenge to implement a feedlot health management program. According to Jim and Guichon (1989), the critical areas that must be considered in the implementation of a successful production-oriented veterinary service to large feedlots include identification of appropriate clientele, acquisition of extensive industry knowledge, a fundamental change in the traditional veterinarian-client relationship, establishment of a framework for program evaluation, and a well-constructed action plan. The client served must want to be involved in profit-oriented feedlot production. The veterinarian must be knowledgeable about the daily operation of a feedlot; this knowledge includes an understanding of cattle procurement, marketing strategies, allocation of personnel, and performance parameters. The veterinarian must also be able to integrate that knowledge with knowledge of clinical medicine, pharmacology, pathology, and economics.

The principal objective of a feedlot health management program is to optimize production and maximize profit, which includes reducing death loss and drug expenditures. In the traditional system of veterinary practice the veterinarian did best financially when the morbidity and mortality rates were so high that the diagnosis could be made, the treatments given, and the drugs dispensed at a profit. Thus there was a potential for conflict of interest. A veterinarian consultant is paid to keep animals healthy. Under a consulting system, the veterinarian directs the animal health program and is paid for professional services in one of several ways. A common method to charge for consultation services is to charge a monthly fee, with both the veterinarian and the feedlot manager agreeing on the frequency of visits, the length of each visit, and the services to be provided. A second method of remuneration is to charge for professional services according to the number of animals in the feedlot over a certain period. With either of these two billing methods, the veterinarian becomes more intimately involved with the health and production problems of the feedlot. There is no time pressure because the charges are based on a preset amount and level of service. Some veterinarians charge for consultation services on an hourly basis. An inherent disadvantage of being paid by the hour is the tendency to rush through the consultation activities, trying to complete tasks as quickly as possible so as not to be perceived as taking advantage of the system. A consultant must have the freedom to use all the time necessary to evaluate the cattle and feedlot operations, to interact with feedlot personnel, to evaluate records in order to determine trends and possible problems, and to train people. Another disadvantage of this billing method is that the costs of consultation services are not predictable for the feedlot.

Most feedlot consultants do not dispense drugs. Many feedlot managers view dispensing as a conflict of interest and prefer that the consultant provide prescriptions (purchase orders) as part of their consulting service, freeing the feedlot to purchase animal health supplies elsewhere. If the consulting veterinarian chooses to dispense animal health supplies, he or she must be extra cautious when recommending products in order to avoid the perception of having an overly vested financial interest.

Program in Action

Constant Surveillance

Constant surveillance by both feedlot personnel and the veterinarian is required. The frequency of veterinarian visits to the feedlot will vary from daily to weekly or monthly, depending on the size of the lot, the management capabilities, the expertise of the animal caretakers, the type of cattle fed, and the nature and prevalence of diseases encountered. A veterinarian can provide several components of a feedlot health and management service; the details of each of these are described.

Regular Inspection

Regular inspection of all areas of the feedlot for possible sources or causes of health problems should be included in a feedlot health service. Errors in animal husbandry should be noted and recorded for discussion with personnel. Attention should be given particularly to the delivery of feed and water, the general well-being of cattle, and any unusual characteristics of each feeding pen. Many feedlot health problems can be attributed to errors in management.

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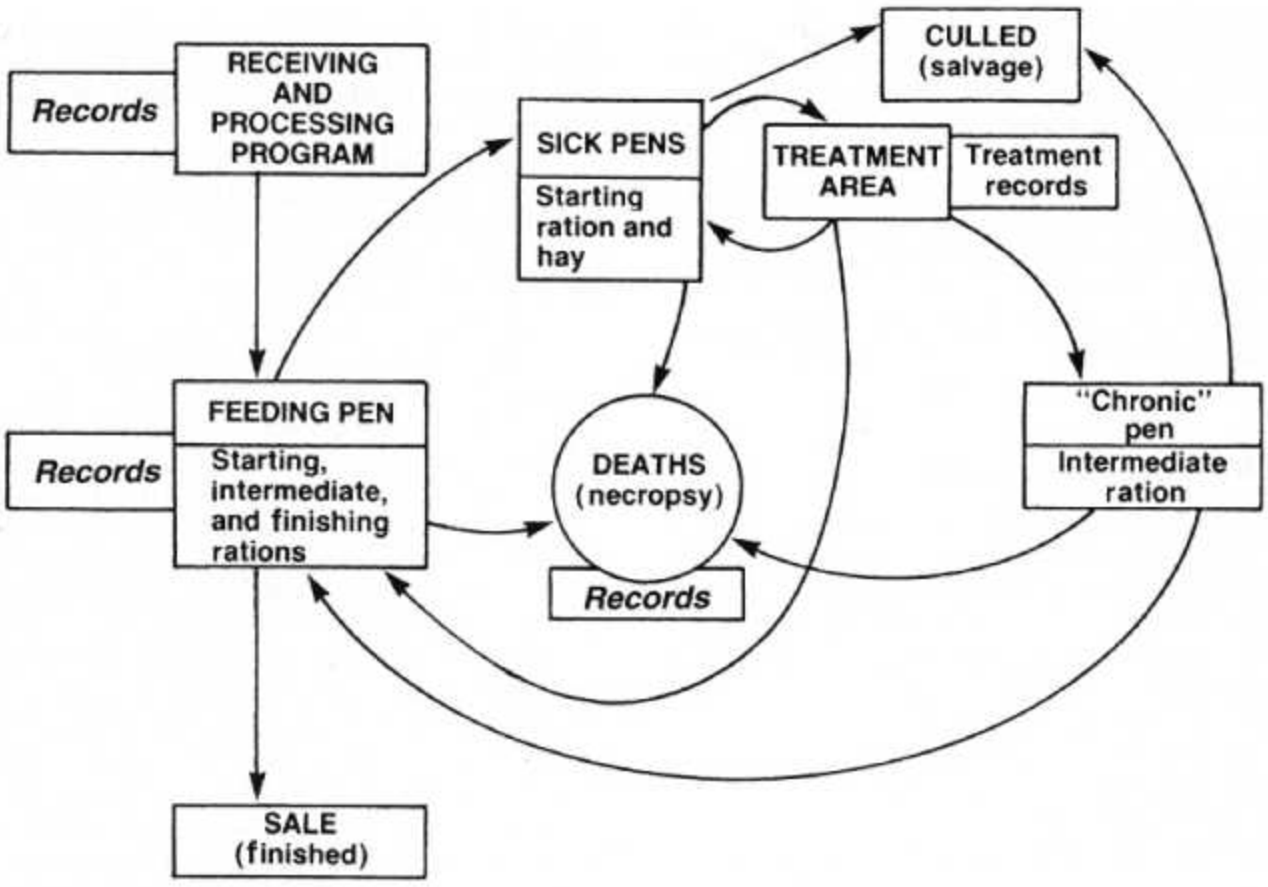

FIG. 14-3 Typical flow pattern of cattle in feedlots.

Disease Surveillance

Continued disease surveillance through regular necropsy examination of all dead cattle and regular observations of sick cattle are necessary. In areas with colder climates carcasses may freeze solid during the winter months before the veterinarian is available. Conversely, in areas with warmer climates, carcasses may decompose beyond usefulness during the hot seasons of the year. When distance prevents the consulting veterinarian from performing a necropsy on every animal that dies, the owner should be encouraged to employ a more accessible veterinarian to conduct regular necropsies. In many cases feedlot personnel can be trained to recognize many common postmortem lesions. Advantages include identification of diseases; confirmation of the clinical diagnosis; evaluation of the effectiveness of the various personnel involved with the health of the cattle, such as the buyer, truck driver, processing crew, pen checkers, treatment crew, feeders, manager, and veterinarian; and evaluation of the effectiveness of specific disease prevention programs and any necessary changes.

An often overlooked method of disease surveillance is monitoring of cattle in the packinghouse. One pharmaceutical company monitors the liver abscess rate for feedlots as a value-added service. The consulting veterinarian can further expand disease surveillance by establishing a relationship with packinghouse management and the government food inspectors so that they will understand the goals and objectives of the visit. When conducting routine packinghouse inspections of cattle for a client's feedlot, it is important to thoroughly understand the "do's and don'ts" allowed in the packinghouse. The primary mission of the packer and the inspectors is to produce wholesome and safe food. The consultant's activities must not and cannot compromise this. Griffin (1994) has described the conduct of routine inspections in a packing plant in detail.

A focal point in the management of disease in the feedlot is fast, accurate diagnosis. This requires a good surveillance system, a careful full-time search for sick animals, appropriate facilities for examination and treatment of sick animals, accurate identification of animals, and appropriate laboratory facilities, especially a necropsy service. A typical flow pattern in a feedlot is illustrated in Fig. 14-3.

Emphasis should be placed on training and supervising feedlot employees in the detection and early treatment of sick cattle. Employees should be given regular instruction in the clinical signs of common diseases. It is the manager's responsibility to ensure that adequate personnel are available to thoroughly inspect each pen at least once and preferably twice daily. It is the veterinarian's responsibility to ensure that these personnel are adequately trained and to monitor or design monitoring systems in order to ensure individual competence.

Surveillance Method (Pen Checking or Pen Riding). Pens of low-risk cattle must be checked at least once daily. Cattle classified as being at high risk of developing respiratory disease should be checked at least twice daily for the first 2 to 3 weeks following arrival into the feedlot. This enables detection of new cases as early as possible, when they are most responsive to treatment. Surveillance can be done from horseback or by walking through the pens, but it is essential to be close and able to move the cattle apart, although this should be done slowly and with the least possible harassment. Pen checking is a skill that requires constant practice and attention to small details.

Method for Checking a Cattle Pen. Once a pen checker knows for what signs to look, he or she needs a system for finding sick cattle and must look at all the cattle in the pen (Fig. 14-4). Experienced feedlot personnel know that sick cattle tend to drift away from healthy animals, and any "loner" deserves some special attention. Sick cattle often can be found around the outside edges of the pen and must be spotted before the checker goes into the pen. Fig. 14-4, *A*, shows how the pen checker can start to identify sick cattle. The most common mistake among pen checkers is to recognize a few sick cattle on the edges and then, instead of

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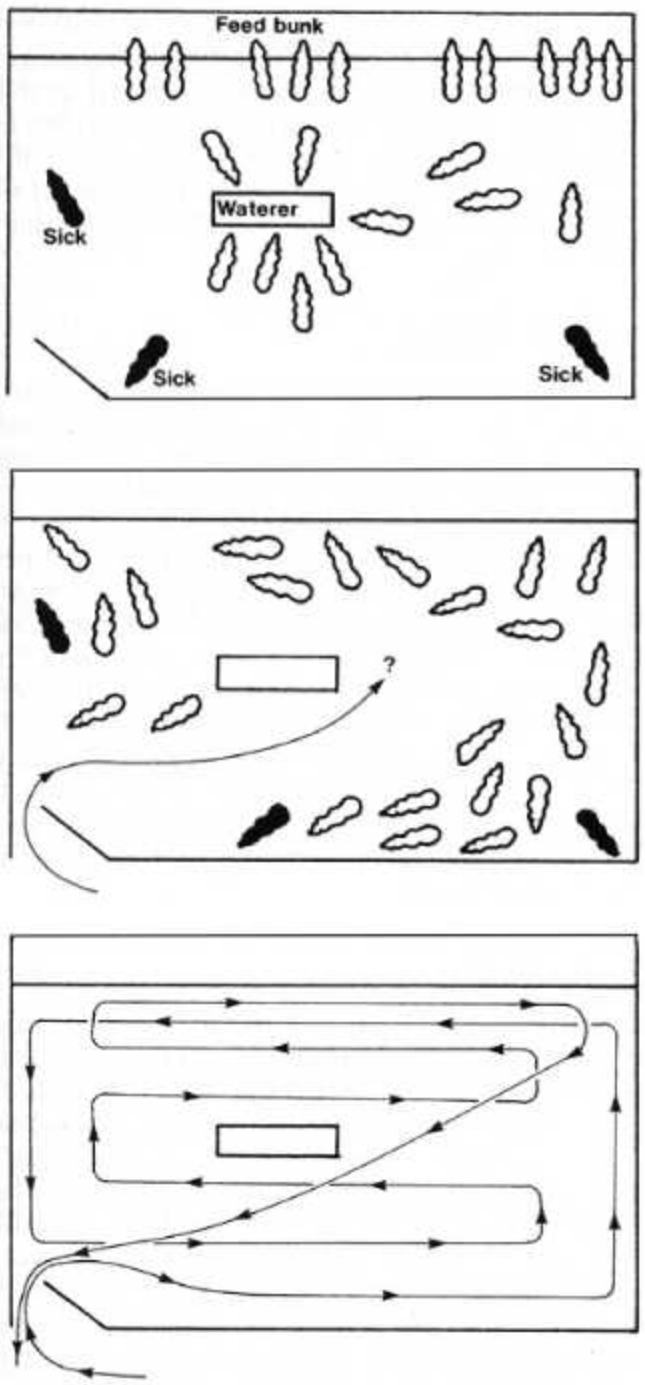

FIG. 14-4 How to walk a pen. **A,** Typical pen. **B,** Wrong approach. **C,** Better method. (From Duff RO: *Cattlemen* September:30-34, 1980.)

marking the animals immediately, to go directly to the center of the pen to stir up the other cattle. This causes the sick and healthy cattle to mix, with the checker usually losing the sick cattle that were on the outside edges (Fig. 14-4, *B*).

The best method of working through the pen is shown in Fig. 14-4, *C*. Note that this gives the pen checker a chance to quietly mark or pull the sick cattle on the outside edges when he or she first enters the pen. Then the pen checker can go on to check the rest of the cattle. By using the pattern shown in Fig. 14-4, *C*, the checker has an opportunity to see all of the cattle from both sides and also can check the waterers, the feed bunks, and any other potential problem areas. The pen checker's list should include the following:

1. Brand or ear tag identification on cattle in the pen: Are there strays? Have cattle been mixed?
2. Conditions in the pen: Are there mudholes that need filling? Is fresh bedding needed?
3. Conditions at the feed bunk: Are feed trucks overrunning high-energy diets at the end of the bunk so that new cattle in the next pen can get to it? What is the condition of the feed in the bunk? Does the bunk need cleaning? Are the water tanks full and operative? Has feed been spilled? Has feed been mixed and the wrong ration fed to the cattle? A pen checker should learn to recognize each diet coming out of the feed mill by sight. Suspicious findings should be reported immediately to personnel responsible for feed preparation and delivery.

The pen checker should be aware of the following:

1. The "loner" animal deserves special attention. However, in certain cases, a sick animal may not be a loner. Nervous system diseases may cause an affected animal to lose its eyesight. When this happens, the animal will actually seek the security of being close to the bodies and sounds of its penmates.
2. The left flank should be observed for fullness. Gaunt, "hollow" animals that are not "filled up" are abnormal. An animal that is not gaining weight or keeping up with its penmates, and any animal that lacks appetite, should be pulled.
3. Some feedlots rotate pen checkers through various sections of the lot. This makes it more difficult to become familiar with the cattle. Pen-checking assignments should be fixed, with each checker assigned to certain pens and having the sole responsibility to check those pens every day. In this way checkers can become familiar with the history of the cattle in these pens and can learn their habits. Fixed assignments also help management. The death loss from certain pens and the response of cattle to treatment allow management to identify efficient pen checkers, as well as individuals who may need extra training.
4. Dark-haired cattle need extra attention. Dark color often masks fine gradations of color that indicate disease in light-colored cattle. Bloody diarrhea is more difficult to spot on a dark animal, especially if the animal is wet. Eye inflammations and tear staining on the face are also more difficult to see.
5. Pen checkers should study the ground, since the character of feces is revealing. Close observation of the rumps helps identify affected cattle.
6. The checker should get the cattle up. The animal that rises, stretches, and defecates is normal, but an animal that does not do these is not necessarily abnormal. However, lame cattle or uncoordinated animals cannot be identified while they are recumbent.
7. Checkers should use other senses in addition to sight. They should listen for labored breathing, groaning, grunting, snoring, sniffling, or coughing. Some abnormal conditions can be detected by smell, such as metritis.
8. Cattle should be observed from a distance. When working a pen, the checker should look at the cattle in the pen behind or ahead. The cattle will be undisturbed and quiet, and sick animals can often be more easily identified from a distance.
9. Checkers should work cattle slowly. Excitement can elevate temperatures by 1° to 2° F, giving the treatment crew an abnormally high temperature reading. When a calf that needs to be pulled is cantankerous and refuses to be separated from its penmates, a second pen checker should be summoned to help in order to reduce the likelihood of injury or additional stress.
10. If a checker is unsure whether an animal is sick, mild exercise may exaggerate symptoms sufficiently to remove doubt.
11. When cattle are found dead in the pens, pen checkers should observe the necropsies, with the veterinarian reviewing the fundamentals of pen checking. This is an opportunity to correlate clinical signs with pathological lesions.

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The selection of pen checkers is important. They need to be keenly observant, knowledgeable, and trustworthy. A good pen rider can maintain surveillance for 5000 to 10,000 head of cattle. When a larger proportion of high-risk cattle are in the feedlot, pen checkers must be assigned fewer cattle because the time to check each pen and pull sick ones is increased.

The signs of ill health that are used to determine the presence of illness are shown in Box 14-2 (Griffin, 1996; Radostits et al, 2000).

Cattle showing these or other obvious signs of illness are examined more closely in the hospital area and, if necessary, treated. In some feedlots, treated cattle are immediately returned to their original pens, whereas in others cattle are kept in hospital pens until recovered. Recovered animals are then put back into their original pens. Most animals that do not recover or that relapse after the first treatment are retreated, although this decision depends on the nature of the disease. The criteria on which further decisions are based are obscure. There comes a time when the expenditure of more money on an animal that is going to be unprofitable is unwarranted. The decision on what course to take depends on whether the animal's life is in danger or the animal is simply doing poorly. If the animal's life is at risk, there is the potential loss of capital invested and all efforts are directed toward avoiding this. If the animal can still be sold and chances of recovery are slim, it is usual to cull it after two or three courses of treatment. This decision is based on the fact that it costs a great deal more, in terms of labor, to keep an animal in the hospital than in the feeding yards, and treated animals should be returned quickly to their own pens or culled. In some feedlots it is the practice to make up a pen of slow gainers, but this can be a nuisance; in most cases the rate of gain is not sufficient to justify the effort.

It is important to closely observe the pens from which sick animals are taken. It is imperative that a potential epidemic be identified early so that pen-level intervention can be considered.

Despite the importance of pen checking, it is not highly reliable for the detection of sick feedlot animals, particularly calves in the first week after arrival. It is difficult to distinguish tired, gaunt calves that may have been weaned a few days earlier from calves affected in the early stage of acute undifferentiated respiratory disease. In some cases up to 50% of animals pulled from a pen of recently arrived calves will not show clinical signs based on measurement of body temperature and a cursory clinical examination. However, more than half of the animals may be febrile at the peak of an epidemic, but less than 20% will display signs of illness. This suggests that the selection of sick feedlot animals based on visual appraisal from a distance may be a random event.

BOX 14-2

Signs of Ill Health

Anorexia: a reluctance to come up to the bunk or a gaunt appearance
Depression: reluctance to rise or move; dropped head and ears; arched back
Lameness or abnormal gait, such as knuckling or dragging of the toes
Stiff movement
Soft coughing; nasal and ocular discharge
Increased breathing rate
Crusted muzzle; sunken eyes
Rough, ungroomed, dry-looking haircoat
Loose or extra-firm feces
Abnormal abdominal fill
Straining; grunting; tail switching

Treatment Protocols

The veterinarian must specify procedures for the clinical management of sick cattle and provide a standard protocol that outlines specific treatments for disease syndromes, including dosages, treatment intervals, routes of administration, and withdrawal times (Janzen, 1990a). The protocol should be followed strictly by all personnel so that the success or failure of therapy can be evaluated accurately and to minimize chances of creating food safety hazards. The effectiveness of the treatment protocol should be evaluated regularly by determination of the response rates for the various treatment regimens. The failure of feedlots to use regular, competent veterinary supervision and to analyze treatment protocols often leads to the use of many different drugs indiscriminately, which leads to treatment overexpenditure and often an increase in the case fatality rate.

Feedlot Records

Records are essential to monitor the incidence of disease, response to treatment, and production performance, and they should be analyzed regularly by the veterinarian and feedlot manager. A wide variety of record-keeping systems are available and are often customized to a particular feedlot (Church, 1980; Janzen 1990b,c,e-g). Records can be maintained manually or by using commercially available computer software.[1-6] Either method is acceptable and has its own advantages and disadvantages. With a manual record system, there is no investment in software or computers, therefore the initial investment is less. Less training of personnel is required, but more time and labor is necessary to initiate, maintain, and analyze records. When records are maintained on a computer, health and feeding software can be interfaced with feedlot accounting software, making billing more timely, efficient, and accurate. Computerized records make the analysis of the animal health program by the consulting veterinarian easier and quicker than manual records.

The necessary input records include the lot description, processing record, lot update, sale information, animal identification, and feed and animal health products purchases. The necessary output records include the numbers of animals pulled from each pen daily, from which an epidemic curve can be drawn; the treatment response report according to pen or drug used; the percentage of pulled

[1]Animal Health Module (AH), Info Tech Division of Walco International, Inc, P.O. Box 1457, Dodge City, KS 67801.
[2]Animal Medical Records, Turnkey Computer Systems, Inc., P.O. Box 9338, Amarillo, TX 79105.
[3]DRUG TRAC Animal Health System, Micro Beef Technologies, Inc., P.O. Box 9262, Amarillo, TX 79105.
[4]Pro Med II & III, Hi-Plains Systems, Inc., P.O. Box 8152, Amarillo, TX 79109.
[5]Vet Records, Lextron, Inc., P.O. Box BB, Greeley, CO 80632.
[6]Guichon-Jim Software, Feedlot Health Management Services, Postal Bag Service No. 5, Okotoks, Alberta, Canada TOL 1TO.

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animals that had a fever, which is an indication of how many are probably affected with an acute respiratory disease rather than a noninfectious disease such as grain overload; the daily mortality report, which should include the list of animals that died, along with their arrival dates, the dates of treatment, and the causes of death; a case abstract of the treatment history of each individual animal; and a close-out summary, which includes all of the costs of production, the health and production performance of the lot or pen of cattle (including morbidity, mortality, ratio of feed conversion to body weight gain, average daily gain), the costs of gain per unit of gain, the number of days on feed, and the profit or loss.

The following text outlines the use of manually generated records. Although most large feedlots have computerized record systems, a discussion of manual records best illustrates the principles of record-keeping, records that are necessary to generate reports, and analysis of records.

Individual Treatment Record (Fig. 14-5). Each animal treated should be individually identified, if this had not been done on entry, and this information recorded on the treatment card. The treatment crew should record the feeding pen, lot number, body temperature, body weight, disease suspected, treatment given, and disposition of the animal after treatment (e.g., which hospital pen). The severity of the illness should be assessed to properly evaluate response to treatment. Late treatment in advanced stages of disease, particularly respiratory disease, is a major cause of failure to respond, even when the treatment of choice is instituted. A card is filled out for each animal that is treated, and all subsequent treatments are recorded on the same card. The cards are filed and retrieved for animals that relapse or die. The cumulative information on the card can be used to decide whether an animal should be culled for chronic or recurring illnesses that are refractory to treatment, to decide on alternative treatments, to explain reasons for death, and, of major importance, to evaluate the effectiveness of the treatments recommended. Some feedlots, especially if they have computerized health records, record animals that are pulled but sent back untreated ("no treat") because they failed to meet the temperature criterion in the case definition for a given disease. This information can be of value if the animal is pulled again or dies. Information on the proportion of pulls that are "no treats" can be used to evaluate pen-checking effectiveness or to let the veterinarian know how a pen of cattle looks to the pen checkers.

SEX _____ BREED _____ SOURCE _____ EARTAG _____

PEN _____

ARRIVAL DATE _____ BUYER _____ LOT _____

DATE	TEMP.	WEIGHT	DRUG	AMT.	DIAGNOSTICS/COMMENTS	DISPOSITION

FIG. 14-5 Individual treatment record.

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Daily Morbidity and Mortality Record (Fig. 14-6). These data should be kept in a central location and updated daily by the pen checkers. This record simply contains the number of treated cattle by pen and lot number, the disease diagnosed, and the date. It provides both the manager and the veterinarian with a rapid assessment of the location of disease problems in the feedlot. It is based on what some call the "daily pull sheet" and contains information on the number of pulls and the number of "no treats," and then classifies those treated according to diagnosis and whether they are a relapse or new case. By using this report in conjunction with an inventory report showing filling dates and numbers added to the pen on those dates, it is possible to generate epidemic curves.

Morbidity and Treatment Analysis Record (Fig. 14-7). This record is an aggregation of data to summarize the morbidity rate, the relapse rate, and the death rate for a lot or pen of cattle. It is especially important as a tool to evaluate the overall effectiveness of the treatment program for various diseases; the relapse rates and death rates are compared with goals set for the feed and with benchmarks published in the literature. The disposition summary alerts the feedlot manager and consulting veterinarian when the chronic or culling rates are abnormally high, which can lead to significant economic losses. A quick glance at the completed form provides information needed for more in-depth diagnostics, training of feedlot personnel, and possible changes in the treatment protocol for specific diseases. The accuracy of the analysis may be improved by correlating the clinical response rate with the results of necropsies and drug sensitivity testing of bacteria isolated from affected animals before treatment (Martin et al, 1983).

Mortality Analysis (Fig. 14-8). The causes of death as determined by necropsy should be summarized on a regular basis. A mortality analysis includes the number of days the animal was in the feedlot, any observed premonitory signs, and treatment of the animal (diagnosis, drug used, and when treated). The location of the animal in the feedlot at the time of death should also be considered. Thus the mortality analysis is based on the individual treatment record and the individual mortality record.

Deaths may be classified as preventable or nonpreventable. Preventable deaths are those that result from inadequacies in management or in the techniques of feedlot personnel. In a large commercial feedlot that purchases cattle from a variety of sources, the personnel that may contribute to feedlot deaths include the veterinarian, pen checkers, feedlot manager, treatment crew, processing crew, feed mill and feeding system personnel, the truck driver who delivered the cattle, and the livestock buyer commissioned to buy the cattle. A regular summary of the possible relationship between death and feedlot personnel allows the manager to institute any necessary changes in management. For example, an unexpected high mortality rate as a result of pneumonia in recently arrived cattle may indicate that the animals were affected with acute or chronic respiratory disease at the time of purchase.

Feedlot Performance Summary (Fig. 14-9). Most feedlots complete a close-out summary for each group of cattle that have been finished and shipped to market. The performance record and feeding summary sections include average daily gain in body weight, total feed consumption, feed conversion ratios and cost per unit of body weight gain, mortality rates, culling rate, and medical costs. The financial summary provides the profit or loss on an individual and lot basis. When the feedlot finances the feed or the cattle, the interest is included in the customer's costs. When comparing costs among feedlots, it is important to know if and how interest is reported in the closeout summary (e.g., whether it is included in the cost of gain).

Vaccination Protocols

An important component of feedlot health programs is the planning of vaccination programs. The necessary vaccines and the vaccination schedule vary depending on the prevalence of disease both in the feedlot area and in the area from which the cattle originated. There is a tendency for feedlots

DAILY MORBIDITY AND MORTALITY RECORD

DATE _____

LOT	PEN	PULLS	NT	P	P1	P2	IP	FR	AR	PE	BU	ME	IT	BL	CO	MI	D
Total																	

Code: NT, Not treated; P, pneumonia; P1/P2, pneumonia relapse; IP, interstitial pneumonia; FR, footrot; AR, arthritis; PE, pinkeye; BU, buller; ME, metritis; IT, ITEME; BL, bloat; CO, coccidiosis; MI, miscellaneous; D, dead (in pen or hospital)

FIG. 14-6 Daily morbidity and mortality record.

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to use too many vaccines in the hope that common infectious diseases will be controlled at a low level. This usually leads to both overexpenditures and less-than-satisfactory disease control. The kinds of vaccines used and the vaccination schedule should be based on the expected incidence of the disease, the cost of the disease when it occurs, the cost of the preventive procedure (vaccine plus labor), the field efficacy of the vaccine, and other available control procedures. All of these factors are based on sound statistical epidemiological data obtained from the disease records kept at the feedlot or at other similar feedlots, continued scrutiny of the scientific literature, and ongoing clinical trials conducted by the veterinarian in these feedlots.

Nutritional Advice

Feedlots frequently consult a qualified nutritionist to assist in the formulation of cost-effective diets. The veterinarian should communicate regularly with the nutritionist to be aware of the composition of the diets and any changes that are being planned. Because feed is the major portion of the cost per unit of body weight gain, it is imperative that the diet be the lowest-cost diet possible while providing nutrients that allow optimum growth and finishing. Most of the emphasis in feedlot nutrition has been on the development of cost-effective diets that support a maximum growth rate without any deleterious effects. Considerable information is available on the nutrient requirements for feedlot cattle and on the feeds and feeding systems used.

The precise specifications of the diets are the responsibility of the nutritionist, but the feedlot veterinarian frequently is in a position to evaluate the quality of the feed delivery system. This means checking to determine whether cattle are fed on time, whether the feed is mixed properly, and whether the feed intake is intermittent because of inclement weather or muddy ground surfaces. Any deviations should be communicated to the consulting nutritionist.

Nutritional deficiency diseases are uncommon in feedlot cattle, because cattle usually receive a diet that contains the nutrients required for maintenance and promotion of rapid growth. Diets prepared according to the Nutrient Requirements of Beef Cattle (National Research Council, 1996) should meet all the requirements under most conditions.

Specific nutrient deficiencies are extremely rare, because diets are prepared every few days or daily and it would be highly unusual for a feedlot to use a feedstuff deficient in a specific nutrient for a prolonged period. However, such a situation may occur in a small farm feedlot that prepares its own feedlot diet with little or no attention to the necessity

Lot No. _____

	ALL CATTLE		RELAPSES		DEATHS	
	NO.	%	NO.	%	NO.	%
NUMBER HEAD						
Steers						
Heifers						
DISPOSITION						
Recovered						
Chronic						
Culled						
Dead						
DISEASES						
Shipping fever						
Respiratory/other						
Foot and leg						
Digestive						
Urinary						
Nervous						
Other						

FIG. 14-7 Morbidity and treatment analysis.

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for supplementation of homegrown feeds. Thus there are only a few nutrition-related diseases that may affect a well-managed feedlot, but these diseases may cause large economic losses when they occur. They include the following:

- Carbohydrate engorgement (grain overload or D-lactic acidosis)
- Feedlot bloat or ruminal tympany
- Feeding errors (i.e., accidental incorporation of an excessive amount of a feed additive, such as monensin or urea, or sudden unintended changes in the ingredient composition of the diet)

Investigation and Clinical Management of Disease Epidemics

In spite of good management, unexpected disease epidemics occur in feedlot cattle. When feeding accidents occur, many animals can be affected suddenly, within 1 or 2 days. In outbreaks of acute infectious diseases, such as infectious bovine rhinotracheitis (IBR), pneumonic pasteurellosis, or *Haemophilus meningoencephalitis*, the first few cases will be followed by a steady increase in the morbidity rate for several days and then a decline as the outbreak subsides 10 days to 2 weeks after the index case.

In some cases, the diagnosis may be obvious (e.g., carbohydrate engorgement caused by a feeding error). However, in infectious diseases of the respiratory tract, the diagnosis may not be readily obvious, and a detailed epidemiological, clinical, and laboratory investigation may be required. A complete investigation may necessitate the involvement of specialists in several disciplines. Every effort should be made to determine the specific source of the disease, since this not only improves the efficacy of treatment and control but also usually generates new knowledge about the disease that may be applicable to future outbreaks.

For most outbreaks of disease in feedlot cattle, more than one method is usually available for the clinical management of the problem and the veterinarian must make decisions that have major economic consequences. The best decision will be made when the most information is available.

The objectives of an investigation are to determine the specific origin and extent of the disease, to take immediate corrective action, and to make recommendations to prevent occurrences (Kahrs, 1978). These objectives are best achieved by systematically delineating the characteristics of affected and unaffected animals within the study population and by observing, recording, and analyzing the distribution of the disease with respect to time, place, and a variety of exposure factors and environmental influences. This analysis must be correlated with thorough physical examination, necropsy findings from representative cases, and appropriate laboratory results.

After completing a general description of the problem, the next step is to confirm whether a problem exists based on the objective information available (Janzen and Ribble, 1990). This can be achieved by answering the following questions:

1. What is the problem, and what percentage of animals are affected? This is the case definition and is vital to the investigation.
2. Who is affected? Defining the group may give a clue to the cause. Recently arrived calves are more susceptible to acute respiratory disease than are animals that have been in the lot for some time.
3. When did the disease occur relative to other recent events in the feedlot? How soon after arrival in the lot did the animals become ill?
4. Where did the disease occur?
5. Why did the disease occur? Hypotheses about the possible causes are formulated on the basis of the observations and data collected.

A complete history should be summarized, including details on the first (index) case, index date, total number of sick animals, treatments given, case fatality rate, population

Time period _____

		DATE				CLASS'N		
ID.	LOT	ARRIVAL	FIRST RX.	DEATH	DIAGNOSIS	P	NP	PREVENTION

FIG. 14-8 Mortality analysis. *NP,* Nonpreventable; *P,* preventable.

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mortality rate, and vaccination history. The origin of the cattle should be determined if possible, and the length of time the cattle have been in the lot may give some clues to a diagnosis. The composition of the feed and whether any recent changes have been made in feeding practices should be determined. A sample of the feed consumed by the affected animals should be obtained and either analyzed or stored for future analysis.

An adequate clinical examination should be performed on several representative affected animals and on some

Owner: _____ Percent ownership: _____

PERFORMANCE RECORD

Lot #: _____ Pen #: _____

HEAD DAYS

Head in: _____ Avg date in: _____ Total: _____

Head out: _____ Close date: _____ Avg: _____

Deaths: _____

	Deads Out	Deads In	Avg	Mean Wt
Weight out				
Weight in				
Total gain				
Average daily gain				

FEEDING SUMMARY

			AS FED	DRY
Total lb fed		Conversion factor		
Average				
Lb/head			DEADS OUT	DEADS IN
Lb/head/day				
Ration cost/ton		Percent consumption to avg. weight		
Cost/head/day				

FINANCIAL SUMMARY

		AVG/HEAD	COST OF GAIN AVG/CWT
Delivered cost			
Feeding expenses			
Feed expenses			
Vet and medicine			
Processing			
Yardage			
Feeding cost			
Total investment			
Sales			
Gross profit (loss)			
Customer's cost			
Interest			
Checkoff			
Total customer's cost			
Net profit (loss)			

FIG. 14-9 Feedlot close-out summary.

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normal in-contact animals. Often there is evidence of early stages of disease in animals that appear normal on distant examination. In cases of infectious disease, appropriate samples (e.g., nasal swabs, blood samples, cerebrospinal fluid samples, and feces) should be taken from affected animals and submitted to the laboratory. Samples for bacterial culture and antimicrobial sensitivity testing should be taken from acute, non-treated cases. Necropsies should be performed on dead animals as soon as possible after death, before postmortem decomposition makes diagnosis difficult.

After the diagnosis has been determined, the rationale for treatment is then outlined. Emergency slaughter for salvage may be the most economical method for the clinical management of diseases such as grain overload. Cattle affected with common infectious diseases (e.g., pneumonic pasteurellosis, *H. meningoencephalitis*) cannot be slaughtered for salvage, and treatment is necessary.

When outbreaks of infectious disease are encountered, the intensity of surveillance must be increased to detect new cases in the early stages of disease when response to treatment is usually good. Detection of clinically affected cattle in the early stages of disease is difficult and requires considerable dedication on the part of pen checkers. Approximately 20% of the cattle that die from pneumonic pasteurellosis are found dead without any premonitory clinical signs; this occurs even in well-managed feedlots.

All of the details of the outbreak should be listed in chronological order and then analyzed and interpreted. Correlations can be made between exposure factors and the occurrence of new cases during the course of the outbreak. Often epidemiological determinants that explain why the disease occurred can be identified. This information can be used to control future occurrences. A detailed report of the outbreak, outlining the conclusion and recommendations, should be prepared and submitted by the veterinarian to the owner.

Undifferentiated Bovine Respiratory Disease

Undifferentiated bovine respiratory disease (UBRD), also known as cattle shipping fever, is the most important disease complex affecting cattle in North American feedlots. The term *undifferentiated fever* (UF) is now considered more appropriate than *bovine respiratory disease* for describing feedlot cattle that are febrile with a lack of abnormal clinical signs referable to a body system other than the respiratory tract (Booker et al, 1997, 1999).

Etiology. The most common pathogen isolated from the lungs of feedlot cattle that die from UBRD is *Pasteurella haemolytica*, biotype A, serotype 1 (Confer et al, 1988). *Pasteurella multocida*, Heddleston type 3, is isolated to a lesser extent. It is generally agreed that *P. haemolytica* is the most important pathogen in fatal pneumonic pasteurellosis, accounting for the majority of cases of UBRD (Haziroglu et al, 1997). However, several viruses, including IBR, parainfluenza type 3 (PI3), bovine respiratory syncytial virus (BRSV), and the bovine viral diarrhea virus (BVDV), can be isolated from the tissues of the respiratory tract of feedlot animals that have died from respiratory disease. A common enteric virus, bovine coronavirus has also been implicated as having a role in BRD (Carman and Hazlett, 1992). *Mycoplasma bovis*, *Mycoplasma dispar*, and other species have also been isolated (ter Laak et al, 1992). It is believed that one or more of these pathogens may play a contributing role in the origin and pathogenesis of the disease in some affected animals (Virtala et al, 1996). According to Yates (1982), lesions virtually indistinguishable from those of shipping fever in the field can be produced experimentally, but the relationship between naturally occurring disease and experimental dosages of viral and bacterial respiratory tract pathogens and the challenge exposure methods used is unknown. Experimentally, *P. haemolytica* A1 is capable of causing the disease as a primary pathogen if the animals are susceptible (i.e., nonimmune) and if the organisms are in the logarithmic growth phase and administered into the trachea or lungs in sufficient numbers (Shoo, 1989b).

Seroepidemiological studies of UF in feedlot calves in western Canada found evidence of exposure to *P. haemolytica*, *Haemophilus somnus*, bovine herpes virus-1, GIV-glycoprotein, bovine viral diarrhea virus, *Mycoplasma bovine* and *Mycoplasma alkalescens* (Booker et al, 1999).

BRSV is widespread and has been implicated as a predisposing factor in fibrinous pneumonia and as a cause of interstitial pneumonia (Collins et al, 1988a,b). In feedlots 92% or more of unvaccinated cattle may be seropositive for BRSV and BVD and PI3 viruses. If cattle enter the feedlot without antibodies to these viruses, they may undergo seroconversion while in the feedlot, even without clinical evidence of disease. Range cattle have more varied exposure to BRSV; the overall prevalence in adult beef cows is about 70%.

Two studies have noted an association between high BRSV serum antibody titers on arrival at the feedlot and a reduced risk of subsequent respiratory disease (Martin and Bohac, 1986; Caldow et al, 1988). Field trials to evaluate immunization of beef cattle before weaning, at weaning, or immediately on arrival at the feedlot with a commercial BRSV vaccine demonstrated a small reduction in treatment rate for respiratory disease that may not be significant (Van Donkersgoed et al, 1990; Hansen et al, 1992). There is a possibility that the disease may be immune mediated and that there may be a relationship between the presence of antibodies acquired from natural infection and the effects of vaccination.

Atypical interstitial pneumonia (AIP), also known as acute interstitial pneumonia, has occurred in association with epidemics of BRSV infections. The pathological findings in cattle with AIP are similar to those reported for acute cases of naturally occurring BRSV infection (Collins et al, 1988a). Recently, experimentally induced BRSV infection has been demonstrated to cause the severe form of disease sometimes observed after natural (Wollums et al, 1999). In acute, fatal, naturally occurring cases of BRSV pneumonia, the principal lesions consist of acute or chronic bronchitis and bronchiolitis in the cranioventral portions of the lungs, combined with widespread emphysema and edema throughout the lungs (Kimman et al, 1989a). It has been suggested that BRSV infection in the cranioventral portion of the lung and the accompanying cytopathological findings are not sufficient to explain the widespread edema and emphysema in the entire lung; an immune-mediated mechanism may also play a role. Such a pathogenic mechanism has been proposed by Kimman et al (1989a,b). During an outbreak of BRSV, calves with or without maternal antibodies are exposed to the virus for the first time. Ciliated and nonciliated epithelial cells in the airways and alveoli in the cranioventral portion of the lung become infected and injured. This process is accompanied by inflammation and repair. The infected cells have altered surface characteristics that activate complement, which may contribute to lysis of these cells and cause the influx of neutrophils. The primary immune response is first detected 8 to 10 days after infection, which may explain the two stages of the disease that are sometimes observed. Activated complement may reach the cranioventral portions of the lung by way of the bloodstream, exerting its spasmogenic effect on smooth muscle and inducing the release of mast cell mediators, which causes severe edema and emphysema in the entire lung, clinically recognized as respiratory distress. There is indirect evi-

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dence for implication of immunoglobulin E (IgE) in BRSV infection (Stewart and Gershwin, 1989). There is also evidence that BRSV infection with 3-methyl-indol intoxication causes more severe lung disease (Ellis, 1998a).

When *H. somnus* was first recognized as a pathogen in feedlot cattle, the most common associated disease was thromboembolic meningoencephalitis. However, fewer cases of the nervous form of the disease are currently being reported, and other disease manifestations are being identified. The *H. somnus* disease complex, also known as hemophilosis, includes several different syndromes and lesions. The respiratory form of the infection has been gaining in importance, and the organism has been associated with laryngitis and tracheitis in feedlot cattle. In recent years, *H. somnus* has been isolated with increasing frequency from the lungs and pleura of feedlot cattle dying with lower respiratory tract disease, and it is currently thought that this organism may be an important contributor to fatal feedlot fibrinous pneumonia (Harris and Janzen, 1989). In case-control studies the organism has been found in pure culture in up to 28% of the cases' pneumonic lungs (Groom, 1989). However, isolation of the organism varies widely on incoming cattle (Van Donkersgoed et al, 1994; Haziroglu et al, 1997). Previous treatment with antibiotics and freezing of the tissues reduce the isolation rate of the organism. Experimentally, *H. somnus* can produce a suppurative pneumonia that resembles the naturally occurring pneumonia thought to be caused by the organism (Jackson et al, 1987; Potgieter et al, 1988). Three new *H. somnus* syndromes are thought to be the result of septicemia occurring without the nervous form of the disease. Acute fibrinous pleuritis in the absence of pneumonia is becoming more prevalent in laboratory submissions (Groom, 1989). Affected animals are found dead without previous evidence of illness or a history of ineffective response to treatment for pneumonia. At necropsy, there is extensive fibrinous pleuritis with mild to moderate pulmonary congestion.

Myocarditis caused by *H. somnus* is being recognized with increasing frequency in feedlot cattle. Affected animals usually die suddenly. At necropsy the typical lesion consists of a darkened, necrotic area with a pale border at the base of the papillary muscle in the left ventricular wall (Guichon et al, 1988). The lesions measure up to 1 × 2 cm in diameter, and small abscesses may be evident when the ventricular wall is sectioned. The cause of death is acute heart failure. Acute pulmonary congestion and edema causing sudden death are also thought to be a form of *Haemophilus* septicemia. Virulence differences exist among strains of *H. somnus,* which may account for the different clinical manifestations (Groom et al, 1988).

Epidemiology. In a 12-month survey of diseases in a large Colorado feedlot, lower respiratory disease accounted for approximately 46% of the total cost of disease and 60% of the cost of the 10 most prevalent diseases (Frank et al, 1988). The incidence of the disease varies widely, but on average, approximately 30% of calves 6 to 8 months old develop the disease 7 to 14 days after arrival in the feedlot (Martin et al, 1988) or after being subjected to stresses such as weaning, commingling, shipment over long distances, and rapid fluctuations of environmental temperature. Within a defined group of cattle, the epidemic curve peaks at 7 to 21 days after arrival and then declines toward no morbidity after Days 21 to 28 (Martin and Meek, 1986). However, some calves are affected with the disease on arrival in the feedlot or become affected within a few days of arrival. Often these animals are of auction mart origin and may have been weaned several days earlier. The epidemic curve suggests that BRD is the result of a point source cause, even though the incubation period may vary. Field observations by feedlot managers and veterinarians suggest that in a large pen containing animals from many different sources, there is a buildup of the number of cases, followed by a decline, known as a propagated outbreak, suggesting animal-to-animal transmission of the responsible pathogens (Wilson et al, 1985). The hypothesis that the disease is communicable within large pens containing animals from different sources seems to have played a major role in the development of control measures such as prophylactic medication and the use of vaccines for immunization against the pathogens. However, there is no evidence that the clinical disease in one individual increases the risk of disease for other cattle in the same pen (Martin et al, 1988).

The possibility that infection with several different viruses and *Mycoplasma* may predispose feedlot cattle to acute pneumonia has been the subject of intense research activity (Perino, 1989). Ample evidence demonstrates that most of the putative pathogens spread rapidly when cattle are assembled at sales yards and feedlots. Direct contact is the most common method of transmission; however, airborne transmission of BHV-1, BVDV, and BRSV is possible (Mars et al, 1999). *P. haemolytica* has been shown to rapidly transfer to susceptible calves even under nonstressful conditions (Briggs et al, 1998). A comparison of the distribution of serological titers of cattle on arrival in the feedlot—with the distribution of seroconversion 28 days later in animals treated for respiratory disease, and with controls not treated—revealed that IBR virus, PI3 virus, BVDV, and BRSV were present, active, and associated with respiratory disease (Martin and Bohac, 1986). The presence of antibody indicates current or recent exposure to the virus but does not indicate resistance. Cattle with low titers to IBR or BRSV were at increased risk for subsequent treatment for respiratory disease. Treated cattle also had greater responses to PI3 or BVDV antibody titers than did control calves. Serologically there is evidence of a high prevalence of *M. bovis* and *M. dispar* infection in feedlot calves (Rosendal and Martin, 1986), but there is insufficient evidence to support an etiological role for the organisms (Martin et al, 1989).

Seroconversion to *P. haemolytica* cytotoxin, BRSV, and BVDV was predictive of respiratory disease, explaining 69% of all respiratory disease cases in small groups of feedlot calves (Martin et al, 1989). In another study incoming calves carried high antibody titers to *Haemophilus* at the feedyard, and high titers were associated with a reduced risk of developing BRD (Martin et al, 1998a). An investigation of the statistical relationship between titers and the health status of feedlot calves at the group level revealed that seroconversion rates to *M. dispar* and BVDV were predictive of increased respiratory disease rates, and seroconversion rates to *P. haemolytica, P. haemolytica* cytotoxin, *M. dispar,* and PI3 were predictive of decreased weight gains (Martin et al, 1990). In a Canadian study, 82% of calves had antibody titer to bovine coronavirus; however, titer change after arrival at the feedlot was not related to the development of BRD or weight gain (Martin et al, 1998b).

Regarding the roles of multiple pathogens in the pathogenesis of bovine respiratory disease, Martin et al (1990) stated the following:

In attempting to understand BRD, it seems sensible to accept that infections involving multiple agents are the rule rather than the exception. Debate may occur about the relative importance of each agent, about the causal structure, and about the best way to break the causal chain/web. However, there should be little doubt that many putative pathogens are active in both individuals and groups during BRD outbreaks, and their effects may go far beyond morbidity and mortality. The apparent effects of these agents should be interpreted in the light of the outbreak situation and the presence of other, non-infectious causes of respiratory

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disease. Until their role is clearly understood, we believe there is much benefit to be gained from studying the presence and activity of microorganisms in "healthy" herd-mates, not just in diseased individuals, and in using groups, such as pens, as the unit of analysis when possible.

Although they are accepted as etiological agents of UBRD, the pathogens described previously are more difficult to manage and cause more severe disease when additional stressors are placed on cattle. Market origin and feeding management can affect the levels and distribution of respiratory disease. In one study of Alberta feedlots, cattle purchased from auction marts and started on high levels of grain were determined to be 6.3 times more likely to be treated for any disease, 4.9 times more likely to be treated for respiratory disease, and 12.7 times more likely to die from respiratory disease than the group made up primarily of farm-assembled heifers and started on a 10% grain ration with time allowed for adjustment to grain (Wilson et al, 1985). This indicates that auction market-derived calves are at greater risk than calves received direct from the ranch, and that certain strategic measures may be necessary to manage and control disease in auction-mart calves. Risk factors affecting morbidity and mortality have been identified previously and include the following (Ribble et al, 1998):

- Mixing of animals from different groups
- Number of calves passing through auction markets
- Time of year when calves are placed in the feedlot
- Weather conditions around the time that calves arrive at the feedlot

The risk factors identified for lower respiratory tract disease in a cohort of feedlot cattle indicated that the disease was more common in steers than heifers; mixing cattle from different sources increased morbidity, and checking heifers for pregnancy within 30 days of arrival was detrimental (Alexander et al, 1989). An increase in the concentration of 2- to 3-μm airborne particles along with wide-ranging daily ambient temperatures enhanced the association between particulate exposure and the incidence of pneumonia (MacVean et al, 1986). The incidence of pneumonia was greatest within 15 days after arrival at the feedlot and during the autumn.

Factors that are known to cause immunosuppression are thought to be contributors. There is strong evidence that a primary postnatal infection of cattle with the BVDV can cause transient immunosuppression, sufficiently enhancing the effect of other pathogens to cause bovine respiratory disease (Potgieter, 1997).

Clinical Findings. The clinical findings of the disease have not been well defined because feedlot cattle with suspected clinical illness are usually not examined thoroughly. Usually there are many animals to be examined, and it is not cost effective to have a veterinarian clinically examine each animal using several diagnostic techniques to improve the accuracy of the diagnosis. Thus the examination is usually superficial. Sick animals are usually detected in the pen, from which they are "pulled" and examined quickly, usually in less than 1 minute in the chute. The emphasis is on measuring the body temperature with a thermometer. Affected cattle are usually depressed and anorexic, may have a gaunt abdomen or may move slowly because of thoracic pain, and commonly have an ocular and nasal discharge. The respiratory rate is sometimes increased, and depending on the stage of the disease, respirations may be shallow and apparently effortless or deep and labored. Coughing may or may not be present. The body temperature is usually elevated to between 39.5° and 41.0° C (103° and 106° F). Although not usually performed in large commercial feedlots, auscultation of the lungs reveals varying degrees of abnormal lung sounds such as loud breath sounds, crackles, and wheezes, suggestive of pneumonia. Lung sounds are usually muffled in cases with a pleural effusion. Some animals may be found dead without any previous sign of illness. Affected animals usually respond to treatment with common antibiotics, but a small percentage do not respond to treatment and relapses sometimes occur after successful therapy.

The clinical findings of pleuritis may vary depending on whether the disease is associated with fibrinous pneumonic pasteurellosis or *Haemophilus* septicemia. Affected cattle are usually chronically ill with fever, dyspnea, and painful respirations. Cattle affected with myocarditis may be found dead without any previous history of treatment for disease. Acute interstitial pneumonia is characterized by severe dyspnea, perhaps mouth breathing, normal body temperature or fever, loud breath sounds on auscultation of the lungs, and a history of nonresponse to treatment.

The details of the clinical findings and differential diagnosis of pneumonic pasteurellosis are given in Radostits et al (1994).

Pathology. Necropsy of individual dead animals in a feedlot is an important means of obtaining daily information on the occurrence of specific diseases and on the efficacy of the animal health management program. The differential diagnosis of feedlot pneumonias has been reviewed by Wikse (1985). The feedlot pneumonias can be categorized according to epidemiology, etiology, clinical findings, and lesion type. This approach enables the clinician to make immediate useful recommendations based on evaluation of the epidemiological, clinical, and pathological findings. The most common pathological findings are bronchopneumonia, fibrinous pneumonia, coagulation necrosis, and varying degrees of the common complications such as pleuritis and pulmonary abscesses (Andrews and Kennedy, 1997). One of the major problems in the diagnosis of feedlot pneumonia has been the assessment of the age of the lesions. Determination of the age of a bacterial pneumonia with some accuracy helps management to assess whether the pneumonia was already present in the animal on arrival or whether treatment failure resulted from late detection or inadequate drug therapy. In one study the degree and extent of necrosis and fibrosis was found to provide the best assessment of the age of the pneumonia (Daoust, 1989). In acute interstitial pneumonia the lungs are diffusely reddish tan, enlarged, and do not collapse. All lobes are rubbery, wet, and heavy. Emphysema is present, primarily in the diaphragmatic lobes, and there is white froth in the trachea. In fibrinous pleuritis there are thick sheets of fibrin over the visceral and parietal pleura. The thorax contains fibrin and straw-colored fluid. In caudal venal caval thrombosis the lungs contain pulmonary arterial aneurysms and abscesses. Blood clots are present in the airways, and a liver abscess near the vena cava contains a thrombus.

Computer imaging technology can now be used to facilitate the capture of feedlot necropsy data. A digital camera is used to capture necropsy images. Subsequently, the images are electronically transferred to a central site for veterinary interpretation and diagnosis (Wildman et al, 2000).

Treatment and Clinical Management. Pen checkers should record pertinent information on cattle presented to the hospital for treatment. At a minimum, this should include pen of origin, tag numbers, color or description of the animal, and a tentative diagnosis. This pull sheet serves as a valuable mechanism for communication between the pen checkers and hospital personnel. This is especially useful when morbidity rates and hospital activity are high. Hospital personnel should observe cattle pulled for treatment while they are still in the holding pens; this provides an opportunity to evaluate the cattle and to observe for clinical signs before they enter the chute, thereby allowing confirmation of the diagnosis made by the pen checkers.

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Once each calf is restrained in the chute, calf identification (pen, lot, tag number[s]) should be entered into the computer or recorded on the treatment card. At a minimum, the date, rectal temperature, clinical diagnosis, drug(s) used, and dosage should be recorded. Body weight and clinical illness score are useful to assess response to therapy.

The treatment regimen should be developed and monitored by the consulting veterinarian. The focus of the treatment program must be on the therapeutic management of BRD. Four methods are commonly used to select the antimicrobials to be used for treatment of BRD (Smith, 1996b):

- Antemortem testing
- Postmortem testing
- Literature (field trials)
- Evaluation of clinical response

Antemortem culture and antimicrobial sensitivity testing (e.g., minimum inhibitory concentration [MIC]) of acute, febrile, untreated cases provide the best information for determining etiological agent, the bacterial susceptibility, bacterial resistance, and the appropriate antimicrobial dosage. Caution must be exercised when trying to interpret culture and antimicrobial sensitivity data from chronic cases, since these are not representative of the bacteria that initiated the disease.

Necropsy examination of dead calves is an important means of conforming or refuting the clinical diagnosis. Concurrent conditions that may hamper treatment response can be identified. The necropsy also provides an opportunity to show pen checkers and hospital personnel the correlation among disease processes, lesions and the clinical signs. The utility of culturing the lungs of chronic, heavily treated calves is suspect at best.

Published field trial results can provide information critical to the antimicrobial selection decision. To be useful the trial must be properly designed, conducted, and subjected to statistical analysis. A description of the type cattle used in the study, management conditions under which the antimicrobial was evaluated, case definition, and time-event relationships are important information to be included in the paper. Proper statistical analysis helps rule out interactions that tend to mask true differences in the efficacy of products being evaluated. Although field observations are important, differences defined in controlled field trials help the practitioner make the antimicrobial selection based on science rather than just a "gut feeling."

Determination of clinical response to treatment is the final method available to select the antimicrobial to treat BRD. Treatment records should be analyzed in each feedlot on a regular basis to determine the overall effectiveness of the treatment program, including response to first treatment, relapse rate, chronic rate, case fatality rate, and cost of treatment. Results are compared with goals established for the feedlot, which are influenced by the background of cattle received, age of the cattle, feedlot personnel, facilities, diet, and weather.

Suggested guidelines for evaluating the clinical response of cattle treated for BRD are shown in Table 14-2. A reasonable goal for response to first therapy is 70% to 80%. An extremely high first-treatment response rate, coupled with corresponding low case fatality and chronic rates, does not always indicate that the treatment program for BRD is successful. A first-treatment response rate of 90% or higher suggests that many calves without bacterial BRD are being treated, which is not cost effective. When faced with this situation, the consulting veterinarian should perform a physical examination of several of the representative calves. Based on the physical and laboratory findings, the proper course of action should be outlined and feedlot personnel should be

TABLE 14-2

Suggested Guidelines for Evaluating the Subpopulations of Cattle Being Treated for Bovine Respiratory Tract Disease (BRD)

If		
BRD Case Fatality*	**First Treatment Response†**	**Consider**
1%-2%	90+%	Too many false positives in the treatment mix
5%-10%	75%-80%	Might be close to the right treatment mix; however, do not rest. There could still be room for improvement in the number of PTLs and false positives in the mix.
Significantly >10%	Around 60% or less	Too many PTLs. Keep in mind that some cattle may be PTLs when they are unloaded.

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PTL, Pulled too late.

*Defined as total BRD mortalities divided by cases receiving therapy for BRD.

†Defined as cases receiving therapy for BRD minus both mortalities and those requiring additional BRD therapy within 21 days of initial therapy.

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trained to respond to the calf's needs accordingly. A first-treatment response rate lower than the goals and expectations for the treatment program should be of even greater concern than one that is too high. A low first-treatment response rate is often associated with a high case fatality rate, high chronic rate, and high treatment costs. Poor initial treatment response forces the use of several courses of antimicrobial therapy, increasing the risk of antimicrobial resistance.

When the first-treatment response rate is poor, the consulting veterinarian must perform a systematic evaluation of the cattle and the health program. The treatment of cattle with advanced lung lesions is the most common cause of poor first-treatment response rates. This can be due to receipt of cattle's incubating disease or being sick on arrival ("stale" cattle), as well as cattle's being pulled too late by pen checkers. Concurrent diseases, especially those that are immunosuppressive (e.g., coccidiosis, salmonellosis, BVD), negatively affect the response to therapy. Proper hospital management is absolutely necessary for treated cattle to recover from disease.

It is tempting to blame a low first-treatment response rate on the antimicrobial being used. Often feedlot personnel go from drug to drug without improved success. The antimicrobial selected is only one component of the success or failure of the treatment program. In an Oklahoma study (Smith et al, 1994), a significant difference in response rate was seen between groups of calves received during the same period, treated with the same antimicrobial regimen, housed in the same feedyard, fed the same ration, and managed by the same people. One group had an 86.1% response to first therapy, whereas calves from a different origin had a 54.9% response rate. The latter group was lower priced, took longer to assemble, and was "stale" on arrival.

In another report, calves that relapsed after first treatment were treated significantly earlier after arrival than those that did not relapse. Relapse is 3.5 times more likely in a calf treated during the first 4 days after arrival than in one treated more than 4 days after arrival. The response, relapse, and case fatality rates showed greater variability among feed lots than among antimicrobials (Bateman et al, 1990).

Combination antimicrobial therapy is often used with hope of improving the response to treatment; this is done mostly without scientific merit. The intent of combination antimicrobial therapy is to "extend the spectrum of activity," which usually suggests a lack of confidence in a single antimicrobial program. In reality, the spectrum of activity of modern antimicrobials is more than sufficient to treat the common BRD pathogens, including mixed infections. A common practice is to use a less costly antimicrobial in combination with a newer generation, more expensive product. There is no rationale for including a product in the treatment regimen that will not stand on its own. Using some antimicrobials in combination can be antagonistic (Apley, 1997b), causing efficacy for the drug combination that may be less than expected from either drug by itself.

Florfenicol is superior to tilmicosin for the treatment of UF in calves that have previously received tilmicosin metaphylaxis on arrival because of the lower chronicity, wastage, overall mortality, and BRD mortality rates (Jim et al, 1999).

Adjunct or ancillary therapy has been commonly used in many feedlot treatment programs. The use of ancillary therapy has been reviewed (Apley, 1997a). There is little scientific evidence to support the use of ancillary therapy in BRD treatment programs. Much of the reasoning to support their use has not come from controlled field trials, but rather from interpolation of human literature and ill-advised logic. Newer generation nonsteroidal antiinflammatory drugs (NSAIDs) show some promise as ancillary therapy (Hellwig et al, 1999), but at this time the field trial data are yet inconclusive.

When a favorable treatment response is lacking, hospital management must be evaluated. Some feedlots have successfully used a treat-return system, whereby cattle are treated and then returned to the home pen on the same day. This greatly reduces the hospital population but poses more challenges for the pen checker because, in the same pen, there are healthy cattle, treated cattle that are recovering, treated cattle that need additional therapy, and first time pulls. Other feedlots have been equally successful when placing sick cattle in the hospital system until they have recovered satisfactorily.

When hospitals are used to house sick cattle, it is beneficial to pen cattle by day of treatment. By doing this, cattle are more apt to "eat alike" and "look alike." Small cattle should be penned separately from larger, more aggressive cattle. Most feedlots do not have adequate hospital space to house cattle during the fall and winter months when morbidity is high. An aggressive effort to continually return recovered cattle to their home pen is essential to avoid overcrowding, which must be avoided because transmission of enteric diseases, especially salmonellosis, is not uncommon when pens are unsanitary. Ideally, 150 square feet of space/head should be provided. Pens should be scraped frequently, and water tanks should be washed twice daily. In northern feedlots windbreaks provide relief from the stress of cold wind, whereas in southwestern feedlots, shades may be necessary to provide relief from extreme heat.

Expectations for the treatment program should be realistic, accounting for the background and age of the cattle, time of year, and feedlot staffing with adequate numbers of trained and motivated people. Goals can be based on past experience (e.g., reducing death loss by a given percentage as compared with last year), published health performance figures, and comparison with other feedlots in the region (benchmarking).

Death loss is largely a function of the morbidity rate. If the pull rate is low, death loss as a percentage of cattle received is generally low; conversely, death losses are higher when morbidity is high. The range of case fatality rates in the literature is from 1.3% to 15.0% (Bateman et al, 1990; Smith et al, 1994; Gorham et al, 1990). A reasonable target for the case fatality rate is 6.0% (Apley, 1997b; Hoar et al, 1998). The case fatality rate, which is defined as the number of deaths in a given period divided by the number of diseased animals in the population in the same time period, is the most useful figure to assess the overall effectiveness of the treatment program, since the relationship between morbidity and mortality is objectively defined.

Control. Satisfactory and economical control of disease depends on successful integration of management techniques and the possible prophylactic use of biologicals and antimicrobials. It is unrealistic to depend on a vaccine, an antibiotic, or a single management technique to control the disease. Successful control begins with the adoption of good management techniques when the calves are still on the farm or ranch, the judicious use of efficacious vaccines, and care in handling and transportation of cattle to the feedlot. The established structure of the feedlot industry in North America often prevents vaccination of cattle before arrival in the feedlot. Epidemic curves of treatment rates of BRD in North American feedlots demonstrate that the greatest percentage of morbidity occurs within the first 2 weeks after arrival, before a vaccine given on arrival can take effect.

Because disease commonly occurs at the time of shipment from the farm or ranch to the feedlot, much attention has been given to reducing the incidence of disease at this time. In North America, this led to the development of the concept

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of preconditioning. The objective of preconditioning was to prepare the weaned calf for the feedlot environment by vaccinating it for all of the common diseases before weaning and by distributing all stressful procedures (e.g., castration, dehorning, branding, and deworming) over a period of time rather than concentrating them at weaning time. Weaning at least 2 weeks before shipment was also considered desirable, although it now appears that a longer weaning period is beneficial. It was hoped that a weaned calf would adjust quickly to the feed bunks and water tanks in a feedlot. Preconditioning has not been accepted widely because its economic value has not been proven. Nevertheless, it appears to positively promote health and thus can be recommended, even though its economic value remains to be determined. Preconditioning is discussed briefly later in this chapter.

Management. The majority of calves produced in North America are produced on smaller farms and ranches. Because cattle are shipped to feedlots in truckload lots, most farms and ranches do not have sufficient numbers of calves of similar quality, weight, and sex to sell in truckload lots. As a result, most cattle are sold through public livestock auctions or sales yards. This has necessitated the development of conditioning procedures in which, after arrival, the cattle are individually identified, treated with a residual insecticide, given an anthelmintic, sometimes injected with a long-acting antimicrobial, and vaccinated for clostridial and respiratory diseases. Some limited field trials indicate that processing may be delayed for up to 3 days after arrival if the workload prevents earlier processing. Delays of 6 days or more may be detrimental (Lofgreen, 1988).

The feeding and nutritional status of newly arrived cattle must assume some importance, but there are little scientific data with which to formulate a sound economic feeding program to promote rapid recovery from shipping stress. Lofgreen (1988) claims that good results are achieved when stressed calves are fed a receiving ration consisting of 50% to 75% concentrate plus native grass hay, both provided on a free-choice basis for 1 week, followed by removal of the hay and continuation of the milled feed for another 2 to 3 weeks, depending on the performance and appearance of the calves.

Enhancement of Immunity by Vaccination. *Pasteurella* bacterins and respiratory viral vaccines have been used extensively in attempts to control BRD (Cardella et al, 1987). Many veterinarians and feedlot owners maintain that vaccination against respiratory disease is an essential component of their disease prevention programs, both to prevent specific diseases of the respiratory tract, such as clinical IBR, and to reduce losses resulting from respiratory disease in the first few weeks after arrival. However, reviews of the literature on the efficacy of available vaccines for the control of BRD concluded that there are little documented data to support their use under feedlot conditions (Martin, 1983; Perino and Hunsaker, 1997). (Efficacy refers to the ability of the vaccine to reduce overall treatment rate or to increase weight gains.)

Recommendations for a vaccine to control UBRD in feedlot cattle are not possible based on the currently available efficacy information. The vaccines are used widely and many anecdotal claims regarding their effectiveness have been made, but there is little scientific evidence based on properly designed field trials that the vaccines are effective and economical in reducing the incidence or the consequences of respiratory disease (e.g., suboptimum weight gains) (Perino and Hunsaker, 1997). Vaccine manufacturers have not conducted studies to evaluate the efficacy of the vaccines against naturally occurring disease in the field using vaccinated animals with unvaccinated animals as concurrent controls. In most cases the vaccines were approved for sale based on tests for animal safety and for potency as measured by a serological response to the vaccine or an experimental challenge in animals in the laboratory.

Because of the paucity of information from properly designed field trials, the practitioner currently must do a risk assessment to determine the need for a particular vaccine and then evaluate efficacy of the vaccine based on published laboratory challenges (Smith, 1992). This is not the most satisfactory way to select vaccines, since laboratory testing does not realistically mimic feedlot conditions. The cost of preventive measures should not exceed the cost of the disease; risk assessment will help the practitioner make the economic decision.

Vaccines to Control Acute Undifferentiated Respiratory Disease. Because fibrinous pneumonia caused by *P. haemolytica* is the most common lesion associated with BRD in feedlot cattle, much of the emphasis has been on the development of effective vaccines for bovine pneumonic pasteurellosis (Mosier, 1997). Based on immunological and microbiological findings in both naturally occurring and experimentally induced pneumonic pasteurellosis, artificial immunization of cattle appears possible. High levels of naturally acquired antibody to *P. haemolytica* have been associated with protection against the disease (Jericho, 1987, 1989).

Calves that recover from experimentally induced pneumonic pasteurellosis possess increased resistance to subsequent experimental challenge. Calves that have been naturally exposed to *P. haemolytica* or exposed by vaccination also develop antibodies. Protection afforded by antibodies is dependent on the presence of specific antibodies. Leukotoxin antibodies are most closely associated with protection against disease. Certain outer membrane protein antibodies also offer some degree of protection against *P. haemolytica* infection (Confer and Fulton, 1995; Confer et al, 1988).

The vaccine has been evaluated in field trials in feedlots in Canada, with varying results. In one trial, the vaccine was used on arrival in fall-placed calves; the pull rate was reduced by 4%, the first relapse rate by 11.9%, and the second relapse rate by 18.7% (Jim et al, 1988). There was an 8.2% decrease in the mean number of treatment days, overall mortality was decreased by 49%, and the mortality rate resulting from fibrinous pneumonia was reduced by 50%. It appeared that vaccinated animals also responded to treatment more favorably than did nonvaccinated animals. Vaccination of recently shipped nonpreconditioned calves in Ontario caused a slight decrease in morbidity, a slight improvement in response rates, and a possibly significant reduction in relapse rates (Bateman, 1988). When the vaccine was combined with an intramuscular (IM) modified live IBR/PI3 virus vaccine, the morbidity rate was increased, the response rate was decreased, and the mortality rate was increased in some groups. More recently, at least two combinations of modified life virus vaccine and *Pasteurella* vaccine have been approved in the United States by the U.S. Department of Agriculture (USDA).

Pasteurella vaccine has been evaluated in a field trial comparing its efficacy in calves vaccinated at the ranch 3 weeks before shipping to the feedlot, in ranch calves vaccinated on arrival in the feedlot, and in auction market calves randomly assigned to either receive or not receive the vaccine on arrival at the feedlot (Thorlakson et al, 1990). The vaccine did not effect a change in morbidity rates or weight gain. Total mortality rates increased significantly, and mortality rates from respiratory disease tended to be increased in ranch calves that were vaccinated at the ranch. In auction market-derived calves the relapse rates were significantly lower in vaccinated calves. The source of calves was a major factor affecting the incidence or effects of BRD. Calves transferred

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directly from ranches to feedlots, regardless of vaccination status, had lower morbidity and mortality rates and better weight gains than calves purchased from auction markets.

Based on the observation that previous infection of the respiratory tract with either IBR or the PI3 virus may predispose cattle to pneumonic pasteurellosis, the vaccination of beef calves 2 to 3 weeks before weaning and of feedlot cattle 2 weeks before shipment to a feedlot has been recommended as part of a preconditioning program. The results vary, but vaccination of calves at 3 to 6 months of age with an intranasal modified live IBR/PI3 virus vaccine has provided protection against experimental pneumonic pasteurellosis induced by aerosol challenge with the IBR virus, followed 4 days later by an aerosol challenge with *P. haemolytica*. It is important to vaccinate calves at least 2 weeks before they are weaned, subjected to stress, or transported to a feedlot. Vaccination on arrival, although commonly done, is not reliable and in one study was associated with increased mortality. An intranasal modified live virus vaccine given to feedlot steers does not cause transmission of the vaccine virus to nonvaccinated comingled animals (Baker, 1989). A *Pasteurella* vaccine combined with an *H. somnus* bacterin and intranasal modified live IBR/PI3 vaccines and administered to beef calves 3 weeks before weaning and shipment did not prove beneficial (Martin et al, 1984). An *H. somnus* bacterin evaluated in a large number of feedlot cattle had no effect on the overall crude mortality rate; however, vaccination appeared to reduce the incidence of fatal disease and the mortality rate during the first 2 months in the feedlot, when the risk of fatal disease onset is highest (Ribble et al, 1988). Crude mortality and incidence of fatal disease onset during the second week were reduced significantly in vaccinated steers. It was concluded that about 17% of fatal respiratory disease in unvaccinated steers could have been prevented by vaccination with the *H. somnus*–bacterin (Ribble et al, 1988). In U.S. trials the use of *H. somnus* bacterins to control BRD have not always produced positive or logical results. Reports on three studies by one research group have shown positive, neutral, and negative outcomes after vaccination with *H. somnus* bacterin (Amstutz et al, 1981; Morter et al, 1982; Morter and Amstutz, 1983). Some challenge studies have been performed using a systemic challenge (Stephens et al, 1984), whereas others have used a respiratory challenge (Groom and Little, 1988). In western Canadian feedlots, *H. somnus* infection is implicated in 40% of all mortality (Guichon et al, 1996), which makes attempts at controlling the disease through vaccination very appealing. The lower incidence of *H. somnus*–related diseases in U.S. feedlots makes the use of the vaccine questionable.

Studies evaluating the usefulness of BRSV vaccine in prevention of BRD have produced mixed results. In a western U.S. field trial, auction origin calves vaccinated with BRSV vaccine were two times less likely (odds ratio = 2.0) to require treatment for BRD than unvaccinated calves (Hansen et al, 1992). Groups of calves with low morbidity did not benefit from BRSV vaccination. A modified live virus BRSV vaccine given to beef calves before weaning, at weaning, or immediately after arrival in the feedlot was associated with a significant reduction in the treatment rate in one of three groups immunized before weaning and in calves immunized after arrival in the feedlot (Van Donkersgoed et al, 1990). The vaccine had no significant effect on the treatment rate in calves immunized at weaning, in calves immunized after arrival in a bull test station, or in yearlings immunized after arrival in the feedlot. Several other trials have failed to show benefit from using BRSV vaccine.

When BVDV and BRSV virus infections occur simultaneously, the respiratory tract disease is much more severe than a BRSV infection alone (Kelling et al, 1995). BRSV infection alone produces mild signs. When mixed infections occur, the value of vaccination with BRSV vaccine may be greater than that demonstrated in field trials. There is more benefit from vaccinating calves entering the feedlot than yearlings.

Some feedlot veterinarians recommend that feedlot cattle be vaccinated on arrival with the *P. haemolytica*, IBR/PI3, *H. somnus*, and BRSV vaccines. In many cases the BVDV vaccine is also used, because some veterinarians feel that the virus is part of the respiratory disease complex. It is believed that control will be achieved if the animals are vaccinated against all of the common pathogens that contribute to lesions of bovine respiratory disease. However, there is little, if any, published evidence based on controlled field trials to justify such action. It is obvious that vaccines are only one of the tools used to reduce the risk of BRD and cannot by themselves predictably control BRD.

Metaphylaxis. Antimicrobials have been used extensively for many years to control pneumonic pasteurellosis in cattle that have just been introduced into a feedlot. The challenge has been to know which groups of animals benefit from metaphylaxis and to know when to administer the drug.

When considering metaphylaxis as a management tool in feedlots, it is necessary to establish objectives for its use. Objectives of antimicrobial metaphylaxis include those found in Box 14-3 (Smith, 1996a).

Obviously, not all groups of newly arrived feeder calves benefit from metaphylaxis. Cattle that have been properly backgrounded and immunized experience morbidity rates that are too low to justify the expense. Lighter-weight, multiple-origin calves are at greater risk of developing BRD than heavier, yearling cattle. Other risk factors for the development of BRD have been reviewed (Young, 1995).

Metaphylactic use of antimicrobials should adhere to the following principles (Young, 1995): (1) the risk of infection is sufficient to warrant the use of antimicrobials, (2) organisms that are involved in the infection should be known or accurately predicted (a logical corollary would follow that the selected antimicrobial has demonstrated efficacy against the organism or organisms), (3) the antimicrobial should be delivered and distributed to the site of infection before the onset of infection, (4) the selected antimicrobial should pose minimum risk of adverse effects, such as tissue damage, (5) the metaphylaxis protocol should be cost effective, and (6) only products labeled for cattle with an established preslaughter withdrawal should be used.

Criteria useful for determining whether to use antimicrobial metaphylaxis on a particular group of newly received calves are shown in Box 14-4 (Smith, 1996a).

Currently, two routes of administration are available: oral and parenteral. Oral medications can be delivered through the water or the feed or as boluses. A disadvantage of administration of antimicrobials through the feed or water is the uncertainty of individual animal intake, since dosage is measured on a pen basis. Administration of products through feed or water offers advantages of minimal cattle handling and less labor and eliminates the likelihood of injection blemishes. The use of boluses is somewhat laborious and time consuming. When boluses are administered to large numbers of calves, such as at processing, the risk of pharyngeal injury is increased. Parental administration of antimicrobials is a viable option in a metaphylaxis program. Products selected should be efficacious, have an established preslaughter withdrawal, and should be tissue friendly. Those with smaller dose volumes are more easily administered (Pollreisz et al, 1991).

One of the first attempts to prevent new cases of respiratory disease was through the administration of sustained-release oral sulfamethazine boluses or benzathine-procaine penicillin to animals after arrival in the feedlot. In the case of

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the penicillin compounds, the results varied; sometimes the short-acting component was effective if the animal was in the early stages of the disease, but the long-acting component was ineffective because the serum concentrations of the drug were not high enough to be effective over the critical period.

In other earlier studies, oxytetracycline at dosages of 5 mg/lb (11 mg/kg) of body weight IM daily for 3 days, followed by oral sulfadimethoxine (68 mg/lb, or 150 mg/kg body weight) on the third injection day reduced the number of treatment days per calf by about 80% compared with controls. The use of long-acting oxytetracycline reduced the treatment days per calf by 90%. Furthermore, administration of long-acting oxytetracycline (9 mg/lb, or 20 mg/kg body weight IM) to feedlot cattle on arrival can reduce the morbidity and mortality from respiratory disease (Albak et al, 1986). IM administration of two different formulations of oxytetracycline to high-risk feedlot calves on arrival reduced the morbidity from respiratory disease during the first 2 weeks on feed and for the entire feeding period by 15% to 19% and also reduced the incidence of fatal fibrinous pneumonia by 67% and 84% (Harland et al, 1991). Long-acting oxytetracycline can reduce the isolation rate of *P. haemolytica* from nasopharyngeal swabs by about 30% during the first week after treatment (Shoo, 1989a).

More recently, two newer antimicrobials, tilmicosin and florfenicol, have been approved for metaphylactic treatment of BRD. Because it has been on the market longer, more data are available from studies using tilmicosin for metaphylaxis than florfenicol. In a summary of 15 trials, Guthrie et al (2000) reported that the use of tilmicosin in high-risk calves at arrival reduced the morbidity rate by 53%. The overall mortality rate was significantly less in calves treated at processing, and gain was improved by 8.4% during an average study period of 60 days. The morbidity rate was reduced in all 15 trials. Differences in mortality and daily gain were less consistent. Delaying the use of tilmicosin metaphylaxis until 72 hours after arrival does not offer any advantages over treatment at arrival (Schumann et al, 1991).

The practice of using rectal temperature as a determinant for metaphylactic therapy has long been debated. If rectal temperature is a useful predictor of illness, fewer animals would be treated at processing, decreasing input costs and antibiotic usage. This concept has been researched but with contrasting outcomes. In the first temperature-based metaphylaxis study, Galyean et al (1994) divided 511-lb (232-kg) high-risk calves into three treatment groups: nonmedicated controls; complete metaphylaxis with tilmicosin at processing; and a temperature-based group where only those calves with a rectal temperature exceeding 39.7° C (103.5° F) were treated with tilmicosin. At 56 days after arrival, calves in the temperature-based and complete metaphylaxis groups gained 0.30 and 0.33 lb (0.14 and 0.15 kg)/day more than the controls, respectively. Feed efficiency was significantly improved in both treated groups. Morbidity was high (44%) in the nonmedicated control group, but it was reduced to 12% and 13% in the complete and temperature-based metaphylaxis groups, respectively. In this study, there were no significant differences in gain, feed efficiency, or morbidity between the two medicated groups; both medicated groups performed better than controls. Temperature-based metaphylaxis returned $3.21 more/head than complete metaphylaxis (Smith, 1996a).

In a larger study (Vogel et al, 1998) calves not medicated at processing experienced a 58.7% morbidity rate and 4.5% death loss during a 211-day feeding period. Calves in a temperature-based metaphylaxis group were treated with tilmicosin at processing if the rectal temperature was 40° C (104° F) or higher. In that group, 49% were treated for BRD and 2.9% died. When all calves were treated metaphylactically, regardless of rectal temperature, the morbidity rate was 34.5% and the death loss was reduced to 1.7%. When performance was calculated on a "deads in" basis, daily gain and the feed/gain ratio of calves in the complete metaphylaxis group were superior to those in the other groups. Dry matter intake was similar in all treatments.

When adequate highly skilled labor is available, temperature-based metaphylaxis can be successful. However, when trained people are in short supply, large numbers of high-risk cattle are received, hospital facilities or space is inadequate, or weather is severe, complete metaphylaxis of high-risk calves is more cost effective.

BOX 14-3

Objectives of Antimicrobial Metaphylaxis

Reduce morbidity. Historically, this has been the most common objective.

Reduce mortality. When research trials are being reviewed, mortality differences are difficult to measure statistically; however, overall, if morbidity is significantly reduced, mortality will also be lower.

Improve performance. It is difficult to justify the cost of metaphylaxis without an improvement in daily gain and feed efficiency.

Improve facilities management. The use of metaphylactic antimicrobials should reduce hospital crowding. This is especially important in the fall of the year when receipts of high-risk cattle are higher and morbidity rates are at their annual peak.

Overcome personnel shortages or inexperience. Antimicrobial metaphylaxis reduces the number of cases of BRD that must be treated on an individual basis. With fewer cattle becoming clinically ill, chances of "missed pulls" are decreased and more time is available to treat individual sick calves.

Improve profits. To be profitable, antimicrobial metaphylaxis should reduce morbidity and individual animal treatment costs, reduce the number of calves that die or must be culled, and improve cattle performance.

BOX 14-4

Criteria for Choosing Antimicrobial Metaphylaxis

Clinical appearance and past history. If the calves look sick or "stale," or if records show that cattle from this source historically have high morbidity rates, metaphylaxis may be indicated.

Morbidity patterns. If the bovine respiratory tract disease (BRD) morbidity rate exceeds 10% on 2 consecutive days, metaphylaxis may be indicated. It is also indicated if the expected BRD morbidity rate exceeds 20% to 25%.

Feed consumption patterns. A decrease in feed intake often precedes a respiratory disease break by about 24 hours.

Rectal temperature. A sampling of the rectal temperature of calves before processing may be helpful. If the percentage of calves with an elevated temperature is excessive, metaphylaxis is indicated.

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Calves treated with tilmicosin at arrival processing have reduced treatment rates as compared with calves receiving preshipment metaphylaxis (McClary and Vogel, 1999). Preshipment metaphylaxis has been used by many auction markets and order buyers in an attempt to reduce postshipment sickness rates. However, when calves are purchased within a 3-day period and shipped by Day 4, arrival metaphylaxis is superior to preshipment programs and equal to combined preshipment and postshipment metaphylaxis. When metaphylaxis is performed at the feedlot, the consulting veterinarian and feedlot staff have control of the total BRD treatment program, thereby ensuring that proper records are completed and that the Beef Quality Assurance and Residue Avoidance Programs are being followed.

Medication of feed and water supplies is an alternative to metaphylaxis through the use of injectable products. In large feedlots, medication of the water supply is not practical because most have automatic watering systems without the capability to meter medication into the water. Medication of feed is a practical method for metaphylactic treatment of BRD. Chlortetracycline offered at 10 mg/lb (22 mg/kg) of body weight for 5 days has been shown to reduce morbidity to a similar level as tilmicosin (Kreikemeier et al, 1996). Feed intake, both on a pen basis and individual basis, should be considered when making the decision whether to treat by injection or in the feed. Metaphylactic treatment using injectables is preferred when calves become ill with BRD in the immediate postarrival period and before they are eating a normal amount of ration. The antimicrobial susceptibility of the microbes causing BRD should always influence product selection.

Metaphylaxis is not indicated for all groups of newly arrived cattle. It should not be used as routine practice, but rather each group of cattle should be considered on its own merit. Metaphylaxis can be a useful management tool, but alone it cannot solve other management problems that affect health and performance of feeder cattle.

CONTROL AND PREVENTION OF DISEASE IN FEEDLOT CATTLE

Successful and economical control and prevention of disease in feedlot cattle depends on purchasing healthy animals; providing a transportation system that minimizes stress, a comfortable feedlot pen environment, and an adequate feeding system; providing a good surveillance system; and judiciously using vaccines and, when necessary, antimicrobial agents.

Feedlot Facilities

Large commercial feedlots that purchase and market large numbers of cattle have the usual facilities for unloading and loading and for weighing and sorting cattle. Some feedlots have starting or introductory pens that are equipped for easy observation and removal of sick cattle. The cattle are fed in these pens until they have adjusted and been processed; then they are sorted and grouped according to size and condition and placed in finishing pens. However, in other feedlots, there are no introductory pens, and the finishing pens are filled to capacity as the cattle arrive. Adequate treatment facilities and hospital pens should be easily and efficiently accessible (Janzen, 1990g). Some feedlots treat sick cattle and immediately return them to their home pen, whereas others choose to hospitalize cattle until they are fully recovered and competitive.

One of the most important considerations in the construction of a feedlot is landscaping to promote good drainage (Janzen, 1990c). The pens and alleyways should be well drained and easily accessible for scraping the ground surface as necessary. Good drainage requires a 6% slope. To avoid overstocking, each animal should be provided with 18 m^2 of space in well-drained land and 9 m^2 in a paved lot.

Cattle and feed need protection from wind, rain, snow, excessive heat, and sunshine. In northern feedlots, snow fences should be constructed with 20% openings and located so that snowdrifts accumulate outside the pens and alleyways. Trees are planted as windbreaks, and buildings and fences are placed so that the wind is not deflected into feeding areas or sheds. An open-front shed provides protection for cattle from winter storms and hot summer sun. Each animal needs about 1 to 1.5 m^2 of cover. The shed should be open to the south or southeast, and the front should be high enough so that the sun strikes the ground at the back on the shortest day of the winter. The back of the shed should be at least 2.5 m high. A covered feed bunk protects feed from weather damage and affords cattle added comfort when eating. Feed remains dry and palatable, and waste is reduced. In southern feedlots, snow fences, windbreaks and sheds are not cost effective because of typically mild winters. Shades to provide relief from extreme summer heat are useful in feedlots in the extreme southwestern United States.

Feedlots and Environmental Pollution

Environmental concerns about feedlot operations have greatly increased in recent years. In the early days of feedlot development, managing the environment to control mud was based primarily on cattle performance and footrot concerns. Dust during the dry season was considered a part of cattle feeding. Environmental management now has increasing priority. Muddy cattle are discounted because of contamination, partly because the abattoirs refuse to pay for the weight added by the mud and manure, but also because of the increased costs to clean the animal before the hide can be removed. Food safety concerns are foremost in the minds of abattoir operators and government inspectors. Foodborne illnesses, particularly those caused by *E. coli* O157H:7 and *Salmonella*, have forced the meat-packing industry to change the way beef carcasses are processed. The packing industry has placed pressure on feedlots to provide animals that are as clean as possible. In addition, stricter environmental laws require that all feedlot waste and run-off be contained in approved lagoon systems. Pollution prevention plans must be on file with the appropriate government agency. Monitoring, testing, and record-keeping requirements vary from country to country and from state (province) to state.

The control of flies is a major concern in many communities. This is generally solved by timely scraping of pens, proper management of stockpiled manure, use of insecticides, and use of wasps that feed on fly larvae. A great deal of money is spent on managing the feedlot environment, especially scraping pens and disposal of animal waste. These costs will continue to escalate with increasing societal concerns over the environment, food safety, and animal welfare.

Transportation of Cattle to the Feedlot

Transportation, or shipping, of cattle has long been associated with increased BRD in the feedlot, hence the term "shipping fever." Today, however, roads are better and trucks are faster and more reliable than those in the 1950s, causing greatly reduced transient times to deliver cattle to their destination. Under the current transportation system, there is not a correlation between the distance cattle are shipped and the risk of fatal fibrinous pneumonia in the feedlot (Ribble et al, 1995c). Apparently other factors such as level of immunity,

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commingling, and other stressors are more important in the risk of BRD than distance shipped.

Obviously, unnecessary stressors should be avoided when transporting calves. Cattle should be handled with a minimum of excitement; this is particularly important for newly weaned calves. Careless handling and transportation of weaned calves can negate any effort the producer may have made to produce healthy preconditioned calves.

Cattle lose considerable weight within the first 24 to 48 hours after weaning, during shipment, and after deprivation of feed and water. This loss in body weight is known as *shrink*. Shrink varies from a minimum of 4% in cattle deprived of feed and water for 24 hours up to 9% in animals that are transported long distances over a period of 2 to 4 days. Some of the shrink is caused by the normal loss of fluids and electrolytes from the digestive tract without normal replenishment. Excitement during handling and transportation increases the total amount of shrink. Most of the fluid and electrolyte shrink can be restored within a few days if the animals begin to eat and drink normally. Tissue shrink also affects cattle subjected to long transportation or excessive handling. Shrink exceeding 7% has been associated with increased animal health problems. The total loss in body weight may not be restored for up to 3 weeks.

Transportation equipment and facilities should meet local standards and be able to transport cattle comfortably regardless of the season of the year. When long trips of more than 24 hours are necessary, calves should be unloaded, fed some good quality dry hay, allowed to drink water, and rested for several hours before continuing the trip. Some countries prohibit the transport of cattle over a certain length of time without unloading for rest, feed, and water. The optimum number of cattle that should be loaded per truck depends on the size of the animals, the size of the vehicle, and legal weight limitations.

On arrival at their destination, the cattle should be examined carefully for evidence of clinical disease or injury. Provision of fresh hay and water can help detect those that are anorexic and should be examined more closely. This is particularly important if unexpected delays in transportation have occurred that increase the level of stress in the animals.

Cattle Purchase and Introduction to a Feedlot

The purchase of cattle and their introduction to a feedlot has been a controversial issue in beef production since the development of commercial feedlots. Commercial feedlots attempt to purchase the most inexpensive cattle that will perform the best and provide maximum economic returns (Van Donkersgoed 1990a,b). However, infectious diseases of the respiratory tract, particularly "shipping fever" pneumonia caused by *Pasteurella* spp., are major causes of morbidity and mortality during the first 30 to 45 days after arrival in the feedlot. Digestive diseases, especially carbohydrate engorgement, in cattle placed on a high-energy diet within 30 days after arrival in the feedlot are a major potential threat but can be controlled. The acute respiratory disease complex is much more difficult to control in feedlot cattle, even under good management conditions.

Epidemiological observations over many years indicate that several factors cause stress, which contributes to the pathogenesis of acute respiratory disease complex in feedlot cattle. The routine process of weaning beef calves at 6 to 8 months of age in North America is often followed by respiratory disease. Any factor that causes additional stress at weaning time leads to an increased incidence of disease. Transportation delays, such as mechanical problems or severe road conditions that slow the trip, are often followed by a herd problem. Rapid changes in weather and unexpected snowstorms at the time of shipping may lead to outbreaks of shipping fever. Recently weaned beef calves 6 to 8 months old that are placed into the feedlot have much higher morbidity and mortality rates than do older yearling cattle. Presumably this is because of the higher level of acquired immunity in older cattle. Mixing or commingling of calves from multiple sources into truckload lots is positively correlated with the risk of fatal BRD (Ribble et al, 1995b). The stress of handling recently weaned beef calves is also considered to be a major factor contributing to shipping fever pneumonia. Cattle are often vaccinated, dehorned, castrated, branded, implanted, and injected with vitamins and antibiotics within a few days after their arrival in the feedlot. The acute respiratory disease complex may remain a major source of economic loss in the feedlot industry if the industry continues the common practice of introducing stressed cattle from different sources, with different immunological backgrounds, into populations of cattle in which disease is endemic.

The major objective is to get the cattle onto a high-energy diet—which will result in rapid growth—as soon as possible, usually within 21 days, while minimizing the morbidity and mortality associated with acute respiratory disease, other common infections (e.g., *Haemophilus* septicemia), and digestive diseases associated with adjustments to high-energy diets. All of these objectives should be achieved as economically as possible.

Origin and Purchase of Cattle

Origin and purchase of cattle is an important phase of feedlot operations. The type of cattle fed are influenced by the cost and availability of feeder cattle, ration cost, expected performance of the animals, and anticipated net financial returns. In North America both calves and yearling cattle are commonly fed. Only a small number of bulls are fed because of the lower market price and the problem of managing bulls in the feedlot. The decision on what kind of cattle to buy and where to buy them is largely a matter of risk aversion. How much risk is the feedlot operator willing to take? It is possible to buy groups of uniform feeder calves or yearling cattle that come from one source and in which the disease incidence will be very low. However, these cattle cost more, and the profit margin is often smaller than that for cattle originating from public auction sales yards. The incidence of disease is much higher in weaned beef calves than in yearling cattle. Steer calves are preferred to heifer calves because of their availability, superior growth rate, higher selling price, and absence of problems associated with estrus and pregnancy in heifers. Lighter-weight calves (less than 500 lb [230 kg]) may be preferred to medium-weight calves (500 to 750 lb [230 to 340 kg]), because they cost less per head and have a greater potential for low-cost gains. Yearlings are preferred in some feedlots, because more groups can be fed per year and the morbidity and mortality from respiratory disease are much lower than in calves. The disadvantages include higher purchase price and higher feed costs per unit of gain. Yearling cattle also may originate from a stocker or backgrounding operation in which calves were placed on pasture or a growing ration for several months. They have adequate body size, gain well in the feedlot, and usually experience minimal health problems.

The principles described in Box 14-5 should be considered when purchasing cattle and introducing them to a highly intensive, heavy feeding environment.

In the simplest system a cow-calf producer weans the calves at 6 to 8 months of age and places them in the home farm feedlot. The calves are gradually brought onto a

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BOX 14-5

Origin and Purchase of Cattle

Only healthy cattle should be purchased.
Cattle should be obtained directly from the farm of origin if possible.
The disease incidence is lower in yearling cattle than in calves.
Adopt the all-in, all-out principle. The cattle are purchased as a group, fed as a group, and sold as a group. This tends to break the chain of infection from one group to another. A corollary to this principle is to avoid mixing recently arrived cattle with cattle already residing in the feedlot. Because of fluctuations in the supply of cattle, feedlots often continue to assemble and make up groups of cattle over a period of several days or a few weeks. When recently arrived cattle are added to existing groups ("add-ons"), new outbreaks of disease occur, which may be perpetuated for several weeks.
Preconditioned cattle should be purchased if economical.
Cattle should be transported to the feedlot in the shortest time feasible.
A reporting system should be developed to regularly inform the cattle buyer of the condition of the cattle received and their subsequent performance. This will assist the buyer in the purchase of healthy cattle, avoiding unhealthy cattle and ensuring that cattle are transported by the most economical and least stressful method of transportation.

growing diet and then a finishing diet and marketed at 14 to 16 months of age. Alternatively, the calves may be kept on a maintenance and growth diet, such as silage or pasture, until they become yearlings, at which time they are placed in the farm feedlot or sold to a commercial feedlot. These calves are usually vaccinated for clostridial diseases and common infectious agents associated with respiratory disease. If these cattle are kept in their original groups until market, the morbidity and mortality rates may be very low and insignificant. However, unexpected outbreaks of diseases may occur even with the best management.

Preimmunization and Preconditioning

The large economic losses associated with the high morbidity and mortality caused by acute respiratory disease in weaned beef calves that were shipped from the ranch within a few days after weaning to sales yards and then to feedlots led to the development of preconditioning. Preconditioning is defined as the preparation of feeder calves for marketing and shipment and may include vaccinations, castration, and training calves to eat and drink in pens (Taylor and Field, 1998). The concept of preconditioning is based in part on immunological and nutritional principles. First, effective immunity against infectious diseases of the respiratory tract can be achieved only if animals are vaccinated in sufficient time before natural exposure occurs after arrival in the feedlot. Preimmunization, or vaccination of calves 2 to 3 weeks before shipment from the ranch to the feedlot, was the beginning of the practice of preconditioning (Hoerlein, 1973). Initially, vaccination before shipment did not appear to provide sufficient protection against disease in calves after arrival in the feedlot. However, calves were still being subjected to stress during transportation and by sales yard procedures. This led to a broader concept of preconditioning. In addition to vaccination, more recent efforts have been directed toward increasing the number of days weaned before movement and improving management procedures on the ranch, such as genetic selection and nutrition, that will assist calves in making an easier transition to the feedlot.

Preconditioning of beef calves means different things in different areas. In the United States preconditioning has been defined by the following elements (American Association of Bovine Practitioners, 1968):

- Weaned at least 3 weeks before sale.
- Trained to eat from a feed bunk and to drink from a trough.
- Treated for parasites.
- Vaccinated for blackleg, malignant edema, PI3, IBR, *Pasteurella*, and sometimes BVD and *Haemophilus*.
- Castrated and dehorned.
- Identified with an ear tag.
- Sold through special auctions.

The following characteristics were used to define preconditioned calves in Alberta (Schipper et al, 1989):

- At least 4 months old before being vaccinated.
- Owned by the operator 45 days before sale or shipment.
- Weaned for a minimum of 45 days.
- Castrated and dehorned at least 3 weeks before sale or shipment.
- Given IBR, PI3, multiclostridial (seven- or eight-way), and *H. somnus* vaccines 3 weeks before sale or shipment.
- Treated for warbles at least 3 weeks before sale or shipment.
- Tagged with an official ear tag applied under the supervision of a licensed veterinarian.
- Accompanied by an official health certificate that has been completed and signed by both the veterinarian and the producer.

A review of preconditioning programs in 12 different states (Miksch, 1985) found good uniformity of management and guidelines based on American Association of Bovine Practitioners (AABP) guidelines. However, controversy continues to surround the issue of preconditioning, the cost, and specific vaccination recommendations. The most important aspects appear to be weaning and familiarity with a prepared ration. Currently, most preconditioning programs have been replaced by individual programs developed at the producer level and by commercial programs, such as Vac 45 (Odde, 1998), promoted by biologics firms.

When preconditioned calves are placed in a feedlot, they usually begin to eat and drink on arrival; if they have not been subjected to unusual stressors, the incidence of disease will be minimal. However, daily surveillance is still necessary to identify cases of illness.

Proper preconditioning of calves involves cost to the primary producer. The rancher must gather and handle the calves early to vaccinate them and, after weaning, must provide an adequate diet until shipment. The loss of weight after weaning must be made up before the sale. If producers are to incur these costs, they must be compensated adequately. Some reports in the literature indicate that preconditioned calves are healthier when they arrive in the feedlot and that the incidence of respiratory disease is lower than in nonpreconditioned calves (Schipper et al, 1989; Karren et al, 1987; Lynch et al, 1997). However, other field studies indicate that the costs of preconditioning do not economically justify paying a premium for preconditioned calves (Peterson et al, 1989a,b).

Cow-calf producers have shown considerable interest in delivering a quality calf to the feedlot but are understandably reluctant to add extra expense unless the returns are greater

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than the costs. The future of preconditioning will depend in large part on whether the livestock industry becomes convinced of its value. In most situations, a premium price is necessary to compensate the cow-calf producer for the costs of preconditioning (Basarab et al, 1986), whereas most buyers are unwilling to pay the needed premium (Engelken, 1997). The real return to management is realized when cow-calf producers retain ownership through the entire feeding period. The real costs associated with sickness clearly indicate a need for integrated health programs (Texas A&M, 1992-1995). Early weaning of calves has a beneficial effect on cow winter maintenance requirements, which must be incorporated into the calculation of the costs and benefits of preconditioning. This suggests that there is a need to examine the economics of the entire system of producing calves for beef production, from the cow-calf producer to the feedlot operator. Currently, the availability of relatively inexpensive antimicrobials and the development of relatively effective postarrival management protocols continue to encourage the shipment of recently weaned calves to the feedlot.

Cole (1985) has summarized preconditioning of calves as follows:

Preconditioning is a theoretically sound concept; however, it has not gained wide acceptance by cow-calf producers or feeders owing to logistics and expense. Many of the claims of preconditioning are not substantiated by controlled research data. Many of the positive claims made for preconditioning may be a result of the calves moving more rapidly through the marketing channels. Although preconditioning is profitable to some producers, on average, preconditioning is difficult to justify economically. However, with the increased numbers of producers retaining ownership through the feedlot, the benefits of the procedure are readily apparent. Modifications of the preconditioning concept have the potential to make it more feasible to the majority of cow-calf producers. Any producer or feeder considering a preconditioning program or feeding preconditioned calves should first calculate an economic projection.

Backgrounding

Backgrounding is a variation of preconditioning in which recently weaned calves are grown to yearling feeder cattle weight, usually in a smaller feedlot. The principal objective is to prepare yearling cattle to adjust to a high-energy finishing ration in a feedlot with minimal problems. This is achieved by feeding the calves a growing diet that yields rapid, efficient body weight gains without fattening. Maximum use is made of roughage rations. The spectrum of diseases that occur in backgrounding operations during the first 45 days after arrival of the calves depends on whether the calves were preimmunized, preconditioned, or obtained from several different sources with no preconditioning. Infectious diseases of the respiratory tract (pneumonic pasteurellosis) and of the digestive tract (coccidiosis) account for most of the losses. Cattle that have been through a backgrounding program usually go onto a high-energy finishing diet in a different feedlot with a minimum of problems. Ideally, groups should be maintained as they were formed in the backgrounding feedlot.

Processing of Nonpreconditioned Cattle on Arrival

The preconditioning concept is a valid one, but it deals with only one segment of feedlot replacements. Ranch calves moving directly to the feedlot are only one source of replacements available to large feedlots. Large commercial feedlots must also rely on public sales yards, where cattle are offered for sale by public auction, and on backgrounding feedlots. Cattle marketed through sales yards may or may not receive the benefit of good animal husbandry practices. These cattle usually originate from a variety of areas. After arrival at the sales yard, commingling of the animals is common, and they are subjected to unfamiliar environments, different feed and watering systems, possibly long periods without feed and water, excessive handling, weighing, and mixed into uniform groups to meet the requirements of commissioned buyers who have specific orders from feedlots. In addition, some cattle may be moved to an order buyer facility, spend several days while other cattle are purchased and resorted for final delivery. As well, calves moving through the sales yards may be subjected to stressors such as castration, dehorning, vaccination, and other processing procedures. All these factors, coupled with exposure to multiple infectious agents, provide ideal conditions for the development of respiratory disease (Rogers, 1997).

From the situation just described, cattle are transported to the feedlot. The trip may require only a few hours or up to 48 hours or more. During this time, the cattle may be deprived of palatable feed and water, and inclement weather may occur. Thus, on arrival at the feedlot, the animals are highly susceptible to acute respiratory disease. The mortality rate in sales yard cattle is approximately 75% greater than that in cattle originating directly from ranches or from backgrounding feedlots. In a vaccine study, auction-market derived cattle were 19.5 times more likely to be treated for respiratory disease than preconditioned cattle, and ranch-fresh calves were 5.7 times more likely to be treated than preconditioned cattle (Hansen et al, 1992).

The processing of cattle of unknown background that have been subjected to the stresses of sales yards and transportation and that arrive at the feedlot at unexpected times of the day and in large numbers (often on a daily basis during the peak buying periods) is a challenge for the veterinarian and veterinary assistants. Cattle may arrive during off-hours because of long travel periods. During peak periods it may not be possible to process all cattle for several days, during which time an outbreak of acute respiratory disease may occur in the animals waiting to be processed. Unexpected shortages in personnel, snowstorms, rainstorms, and unforeseen problems elsewhere in the feedlot all contribute to the vulnerability of recently arrived cattle. There will be wide variations in nutritional status, genetic potential, vaccination history, and colostral immunity. Some cattle will have been castrated and dehorned, and the age at which they were castrated and the completeness of the castration will vary considerably. Some will have come from backgrounding yards, order buying facilities, and range; others will have come from geographical areas in which the incidence of siliceous urinary calculi is high; and some will have been implanted with anabolic steroids. Feedlot heifers may have been fed melengestrol acetate (MGA) to suppress estrus, whereas other heifers may be pregnant. These cattle must be conditioned during the first 2 to 3 weeks in the feedlot.

It is generally agreed in the feedlot industry that recently arrived cattle of unknown backgrounds require extra surveillance and care during the first 2 to 3 weeks after arrival. Most of these cattle must be vaccinated as necessary, and some need to be castrated, perhaps dehorned, and given growth promotant implants. Veterinarians have traditionally adopted the approach that nonpreconditioned stressed cattle of unknown backgrounds should be allowed to adjust to their new surroundings for up to 3 weeks after arrival. During this adjustment period the cattle are fed good-quality roughage along with a quantity of a highly palatable, nutrient dense, ration. The calves must be ensured an adequate water supply and provided with adequate bedding,

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especially during the first few days, so that they can rest. The cattle are checked carefully at least twice daily for evidence of illness, and sick cattle are identified and treated. The provision of only good-quality roughage for the first 2 or 3 weeks has been considered a logical practice. However, controlled field trials in feeder calves subjected to marketing and shipping stresses indicate that increasing the concentrate or energy level in the starting diet to up to about 72% improves performance when compared with lower-energy diets (Lofgreen, 1988).

Large commercial feedlots with experienced personnel may challenge recently arrived cattle with high-energy diets within 2 weeks after arrival. This is done in an attempt to get them on full feed as soon as possible, and economics is the motivating force. However, this system is something like walking a tightrope: most of the time it is successful, but occasionally it is catastrophic. Over the long term, in large feedlots with a large turnover, it may be economical. In small farm feedlots with less experienced personnel, a more conservative approach is recommended.

The major objectives of the feeding program during the introductory period are to get the animals eating, to avoid outbreaks of carbohydrate engorgement, and to avoid outbreaks of indigestion during the period when the cattle are most susceptible to acute respiratory disease. The conservative approach is to provide a highly palatable roughage or silage diet for the adjustment period. After this starter diet, and when the animals are healthy and the common infectious diseases are not a problem, the animals can then be fed the growing and finishing diets.

In the Bruce County Project in Canada, feeder calves were shipped from western Canada to Bruce County in Ontario and placed in small farm feedlots, usually on a one-time basis for the year. Results indicated that the highest mortality rates were associated with the feeding of corn silage rather than hay and with the processing of cattle on arrival (Martin et al, 1980, 1981, 1982). Vaccination against respiratory disease on arrival also appeared to increase the risk of mortality.

Currently, vaccination against certain respiratory diseases within 24 hours of arrival is standard practice for the majority of feedlot and backgrounding operations. The recommendations in Box 14-6 for handling high-risk nonpreconditioned calves are based on experience, efficacy trials, and limited field studies.

Studies by Lofgreen (1988) of the energy level of the diets offered to stressed feeder calves after arrival in the feedlot indicate that diets containing 50% to 75% concentrate promote more rapid recovery of purchase weight than diets containing 25% concentrate. However, diets containing levels higher than 75% appear to increase morbidity and mortality rates from respiratory disease.

In summary, there is a lack of good scientific information to conclude whether nonpreconditioned cattle will benefit from vaccination procedures given within 24 hours of arrival. However, even in the absence of good information, most veterinarians will conclude that the prevention of at least the viral diseases through vaccination is worth the perceived risk of the added stress (Johnson, 1985). In addition, with the use of injectable antibiotics in metaphylaxis programs, processing on arrival can be highly beneficial (Vogel et al, 1998; McClary and Vogel, 1999).

Regardless of the system used, immediately on arrival the cattle should be weighed as a group, examined for evidence of illness, and treated if necessary. Some feedlots administer antimicrobials to all calves considered to be a high risk for acute respiratory disease (Albak et al, 1986). If the illness appears different from the usual case of respiratory disease, a veterinary diagnosis should be sought at the earliest possible time. Close examination and surveillance are desirable for groups of cattle with a history of unusual stress. The youngest and smallest cattle often need special attention, and it may be necessary to separate them from older cattle. All of the available history on each group of cattle should be obtained if possible. A reliable history of vaccination, vitamin injections, implants, and anthelmintic administration would be useful but is usually not available. The major objective during the first few days should be to avoid unnecessary deaths from diseases that normally respond well to treatment. Depending on the condition of the cattle, it may be difficult during the first few days after arrival to easily distinguish sick cattle from healthy cattle, and careful clinical surveillance every few hours may be necessary. Observations at the time of feeding often reveal anorexic animals that should be pulled from the pen and examined.

BOX 14-6

Recommendations for Handling High-Risk Nonpreconditioned Calves

- Feeder calves from different sources or arriving at the feedlot over a period exceeding 7 days are expected to be at high risk of developing respiratory disease and require extra manpower and attention. One person/500 head during this early arrival period is approximately the right ratio.
- High-risk feeder calves should be kept in groups of less than 100. This facilitates early identification of sick calves and minimizes the possible spread of infectious agents.
- Feeder calves should be fed dry, good-quality hay for at least 2 to 3 days. Hay should form the major component of the roughage during the first week.
- Silage should be introduced very gradually and should not become the major roughage during the first 2 weeks after arrival. Preferably it should be limited until the initial upsurge of treatments for illness is over.
- The use of metaphylactic antimicrobials against respiratory disease may be necessary, since it is associated with decreased morbidity and mortality.
- Feeder calves should be processed on arrival if possible; processing should be limited to procedures that are the least stressful to the animal.
- Vaccination with viral vaccines on or shortly after arrival is likely necessary and beneficial. Vaccination should be limited to those products that actually reduce the losses resulting from respiratory disease. Other procedures and products should be delayed for at least 2 to 3 weeks.
- Regular surveillance is necessary to detect and treat sick calves in the earliest stage of disease.
- Handling facilities should be designed to minimize the stress associated with all of the processing procedures to which feeder calves are subjected.

Specific Processing Procedures

Identification. Each animal must be identified immediately, preferably with a color-coded and numbered plastic ear tag that is easily visible from a distance. This is recorded in the record system and, when available, directly into the computer. The color coding allows the attendants to sort and return cattle to their pens, which are indicated by the color code. In many feedlots each animal may not be identified individually but instead receives a tag with a lot number

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(group) or pen number. This identifies individual animals as belonging to a group or pen but not as individuals. Some commercial feedlots also brand their animals to identify ownership, but hot branding should be discouraged. Systems are now in place that individually identify animals with electronic identification tags. Tag readers are available that can read tags from a distance of 8 to 10 inches. Information can be maintained on individual animals through this technology, including performance, vaccine, and treatment history. These tags remain on the animal until slaughter, at which time a transfer of the identification from the ear tag to the overhead trolley system can be made. Individual identification of each animal, when removed from the pen, allows the practitioner to monitor every animal selected for clinical examination (e.g., whether it had a fever and whether it was treated, including the dates of occurrence). The data can be used to monitor the daily incidence of disease for each pen and for the number of days in the feedlot. These epidemic curves provide useful epidemiological information on how soon after arrival animals become ill. From this information, strategies for the treatment and control of acute undifferentiated respiratory disease can be formulated.

Measurement of Body Temperature. On arrival, some animals may be affected with acute disease, but clinical signs will not be obvious. Many animals will appear fatigued and gaunt but are not affected with clinical disease. It is difficult to distinguish these animals from those with acute infectious disease that should be treated and identified early to minimize mortality. The body temperature of high-risk cattle (e.g., auction mart calves or calves that have been transported long distances over several days) is often measured shortly after arrival, usually at processing. Currently available digital thermometers can register the rectal body temperature of an animal in a few seconds. Animals with a temperature greater than 40° C (104° F) are treated with an antimicrobial. Treated animals may be tagged and noted in the individual animal database or alternatively the total number of animals treated (total amount of drug administered) in a group or pen. Even with treatment of febrile animals on arrival, the case fatality rate may approach 10%, which suggests that animals that are sick on arrival have probably been ill for a few days.

Vaccination. The value of vaccination of feedlot cattle for common infectious diseases, particularly those of the respiratory tract, has been controversial since the introduction of the vaccines. A review of the literature by Martin (1983) examined the published evidence for the claims that vaccination with respiratory disease vaccines actually prevents respiratory disease or influences weight gains in feedlot calves. He concluded that little published data support the use of vaccines against respiratory disease under feedlot conditions. Treatment rates and weight gains usually did not differ among vaccinated and nonvaccinated groups. In fact, the use of live BVD vaccines was associated with a significant subsequent increase in treatment rates. In a review of respiratory vaccine literature (Perino and Hunsaker, 1997), the authors reviewed BRSV, IBR, BVD, and *Pasteurella* studies. Field studies demonstrating effectiveness of vaccines in reducing clinical outcomes of respiratory disease are rare, and yet they are a major focus of veterinary health programs.

Questions exist about the necessity of BRSV vaccines. However, vaccine efficacy appears adequate when modified live vaccines are used. Vaccines against the IBR virus have been used for over 30 years. Some earlier studies indicate a reduction in clinical disease with the use of vaccines. Most practitioners would agree that IBR vaccines must be a part of respiratory disease protection (Perino, 1998). The most controversial virus fraction attributable to respiratory disease is BVD. BVD is a disease of cattle that is still not completely understood. Two options exist to treat BVD: eradicate it or vaccinate against it. In the United States, eradication is a long way off and vaccination is a necessity. The choice of vaccines to the veterinarian and producer are modified live or nonreplicating vaccines. It is becoming clear that modified live vaccines provide the best protection against BVD infection and disease (Ellis, 1998b). The use of *Pasteurella* vaccines in the feedlot continues to be a source of debate. Improved vaccine technology has led to vaccines that now contain antigenic components and protect lung tissue from the effects of *Pasteurella* infection. The basic issue to decide is whether the vaccine will provide protective immunity before the time of greatest *Pasteurella* challenge in the feedlot. Efficacious data on *Haemophilus* immunization strategies are limited, but vaccines may provide some protective effect (Van Donkersgoed et al, 1993).

Nevertheless, a wide variety of vaccines are used in feedlot health programs. Veterinarians have decided, based on their clinical experience, that certain vaccines appear to be efficacious, and they recommend their use. In some cases the feedlot operator is convinced, based on experience, that certain vaccines are efficacious, and thus they are used routinely.

Vaccines are available for the following diseases or infections of feedlot cattle:

- IBR
- Pneumonic pasteurellosis
- PI3 virus infection
- BRSV
- Disease complex caused by *H. somnus*
- BVD

The vaccines available for clostridial diseases are highly efficacious. The number of antigens to be used (two- or eight-way) depends on local prevalence of clostridial diseases. These diseases include the following:

- Blackleg *(Clostridium chauvoei)*
- Malignant edema *(Clostridium septicum)*
- Bacillary hemoglobinuria *(Clostridium novyi,* type D *[haemolyticum])*
- Infectious hepatitis (*C. novyi,* type B)
- Tetanus *(Clostridium tetani)*
- Enterotoxemia (*Clostridium perfringens,* types B, C, and D)
- Leptospirosis (*Leptospira serovars hardjo, pomona, grippotyphosa, canicola, icterohaemorrhagiae)*

Vaccines for leptospirosis in receiving calves are usually not necessary; however, in some areas leptospirosis is endemic and vaccination may be necessary. Vaccines reduce clinical cases of leptospirosis but do not prevent all infections.

A basic vaccination schedule for receiving calves should include a four-way respiratory viral vaccine plus a clostridial vaccine. Additional vaccines should only be included if two criteria can be met: The disease is enough of a risk that prevention is necessary, and efficacious data can be found to support the use of vaccines to prevent disease.

Castration and Dehorning. These surgical procedures are frequently performed at processing but are very stressful to cattle and may reduce performance for up to 90 days and increase the mortality rate (Cole, 1985). It is generally recommended that these procedures be delayed until the animals are adjusted to the feedlot.

Management of Pregnancy in Heifers. Pregnant heifers entering the feedlot are recognized as an economic liability. Economic losses occur from death at calving or from infection, increased treatment costs, additional labor (e.g., to check and calve-out pregnant heifers), and reduced value when sold. The dressing percentage of pregnant heifers and heiferettes at slaughter is reduced from 4.0% to 6.1% (Bennett, 1984; Edwards and Laudert, 1984; Stanton et al, 1988). Dressing percentage has a significant impact on the value of cattle sold on a carcass basis.

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There are four options for risk management of pregnancy in feeder heifers (Bennett, 1984; Edwards and Laudert, 1984):

1. Buy only heifers that are confirmed open or spayed.
2. Pregnancy-check at point of purchase and sell-back of pregnant heifers.
3. Purchase heifers that are not pregnancy checked at point of purchase (no pregnancy check or abortion at the feedlot).
4. Pregnancy-check heifers at the feedlot and attempt to abort the pregnant ones.

Spayed or confirmed nonpregnant heifers pose the least pregnancy liability risk. Nonpregnant heifers also gain better than those pregnant and aborted or those pregnant and not aborted. Heifers purchased as nonpregnant, or open, should have been examined by a veterinarian, and documents verifying the pregnancy status of the heifers should accompany the shipment.

Losses incurred with either the sell-back or pregnancy-check/abortion option are similar: $8.29 and $8.71 (U.S. dollars), respectively (Table 14-3). The economic risk is greater when using the sell-back option, where those found pregnant are sold and not fed, as compared with the pregnancy check/abortion program. When heifers are palpated and aborted in the feedlot, death losses can be both unpredictable and excessive, especially when groups of heifers experiencing high BRD morbidity rates are aborted, when weather is severe, or both. Economic losses are greatest when no pregnancy management program is in place. Assuming a 16.5% pregnancy rate, the total loss averaged across all heifers in the group is estimated to be $19.04 (U.S. dollars)/head.

When choosing the pregnancy check/abortion management option, heifers pregnant 120 days or less can be aborted successfully using prostaglandins at label dosage. The abortion rate in heifers pregnant over 120 days and treated with prostaglandins alone can be quite low. Those pregnant over 120 days treated with a combination of prostaglandin and 20 mg of dexamethasone will have an abortion rate of about 95 percent (Edwards and Laudert, 1984; Mapletoft and Barth, 1983). Heifers at high risk of BRD should not be injected with abortifacients for at least 21 days after arrival, since heifers that have been aborted recently and suffer BRD are at greater risk of dying (Edwards and Laudert, 1984; Mapletoft and Barth, 1983). MGA should be withheld from the ration for at least 7 days before and after injection (Clay, 1996).

At times feeding heifers can be more profitable than feeding steers. Pregnant heifers are a liability, and if a pregnancy management program is not in place or is not properly executed, losses resulting from calving, abortions, and associated losses can be economically devastating. The economic returns from a pregnancy management program are greatest when heifers are sold on a carcass basis, since dressing percentages and carcass weights strongly influence sale value.

Spayed Heifers. Spaying (ovariectomizing) heifers is a commonly used method to prevent pregnancy in heifers under range conditions. During the period when brucellosis in cattle was endemic, spayed heifers from infected herds could be marketed for grazing or feeding whereas intact heifers could not. Under current regulations, spayed heifers from Mexico can cross into the United States for feeding purposes whereas intact heifers cannot.

The comparative performance of spayed and intact heifers has been reviewed (Rupp and Hamilton, 1995). When a growth promoting implant is not used, intact heifers on finishing rations gain 6.05% more than spayed heifers. The use of a growth promoting implant can overcome this effect and allow the spayed heifer to gain comparably to the implanted intact heifer. Spayed heifers implanted with estradiol benzoate (EB) or a combination of EB and trenbolone acetate (TBA) gain the same as intact heifers implanted with EB and TBA combination (Perino et al, 1995). More attention should be given to reimplanting schedules for spayed heifers, since their performance drops markedly when no active implant is present.

When spaying is performed by an experienced practitioner, complications are usually minimal. Occasionally

TABLE 14-3

*Economic Comparison of Pregnancy Management Options for Feedlot Heifers**

	Sell Back	No Treatment	Pregnancy Check/Abortion
FEEDING PHASE			
Loss/head: all cattle	$8.29	$15.32	$8.02
Loss/head:pregnant (at purchase)	$50.24	$92.87	$45.58
SLAUGHTER			
Loss/head: all cattle	—	$3.72	$0.69
Loss/head: pregnant (at slaughter)	—	$30.00	$30.00
COMBINED LOSS			
Loss/head: all cattle	$8.29	$19.04	$8.71
Loss/head: pregnant (at purchase)	$50.24	$115.42	$52.76

Adapted from Bennett B: *Proc Acad Vet Consult* 12(1):14-27, 1984.
*Losses are calculated in relation to open heifers. Each calculation assumes a 16.5% pregnancy rate.

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problems resulting from spaying are seen in the packing house. Peritonitis, adhesions of the skin to the body wall when flank spayed, and body wall abscesses are occasionally found. Pregnancy is rare in spayed heifers. If the surgeon left one ovary or a piece of an ovary, the heifer could become pregnant. If the heifer is in late gestation when spayed, she could carry the fetus to term. Either of these problems is minimized when spaying is performed by a competent, experienced surgeon.

There is no need to feed MGA to spayed heifers. This offers another small economic advantage to the spayed heifer.

Anthelmintics and Insecticides. Anthelmintics and insecticides are administered according to local conditions. The feedlot operator and veterinarian should be informed about feeder calves or yearling cattle that have originated from farm situations or areas in which intestinal parasitism is likely. When compared with treatment with a topical organophosphate, treatment with ivermectin can cause improved average daily weight gain and feed conversion in feedlot calves under commercial conditions (Bauck et al, 1989). Young cattle raised on small farms in which the stocking rate on pasture is high may harbor helminths (Armour, 1980). Young cattle may also be affected by chronic verminous pneumonia caused by *Dictyocaulus viviparus*.

Growth-Promoting Agents. Growth-promoting agents are substances that promote increased growth rate of animals without being used themselves to provide nutrients for growth (McCutcheon, 1989). They are generally administered in small amounts with a view toward altering metabolism so that the animal increases body tissues and grows more rapidly. They are anabolic, nonnutritional substances that cause a beneficial change in growth-related phenomena. They promote changes in composition, conformation, mature weight, or efficiency of growth, although these effects are frequently accompanied by changes in the rate of live weight gain. Despite their varied origin and chemical nature, these agents influence the growth process in three general ways:

1. By stimulating feed intake, thereby increasing the supply of nutrients available for growth. Antibacterial agents, estrogens, androgens, and possibly somatotropin increase voluntary intake of feed.
2. By altering the efficiency of the digestive process, thereby improving the supply or balance of nutrients derived per unit of feed consumed. These agents include the antimicrobials (e.g., the tetracyclines, which are fed at subtherapeutic levels, and the ionophores, such as monensin, lasalocid, and laidlomycin, which cause a major shift in the ratio of volatile fatty acids produced in the rumen).
3. By altering the manner in which the animal uses or partitions absorbed nutrients for specific growth processes. These agents include steroids such as estrogens and androgens that promote growth in animals and the β-adrenergic agonists, a class of compounds similar to adrenalin; the best examples are ractopamine, zilpaterol and cimaterol. They improve live weight gain and feed conversion efficiency, increase carcass protein content, reduce carcass fat, and increase carcass yield.

Implants. The efficacy of estrogens and androgens as anabolic agents in increasing live weight gain has been shown in many different growth trials under different husbandry and feeding systems. The best performance results in the feedlot are obtained in steers and heifers treated with preparations combining an androgen with an estrogen. It has become a common practice to implant steroids more than once during the finishing period of beef cattle. The steroids are effective in calves as well as yearlings, and reimplantation extends the period of their effect on growth (Reynolds, 1980).

Long-acting anabolic steroids should not be implanted into animals intended as breeding stock. Changes in behavior after implanting can also be a problem. The incidence of mounting and riding in steers implanted in feedlots has increased with the increased use of anabolic agents. Regulations governing the use of implants are set by the U.S. Food and Drug Administration (FDA). Practitioners must always read and follow the manufacturer's directions before implanting any cattle. The growth promotant implants approved for use in the United States are extremely safe for both producers and consumers of beef. There is no required withdrawal time for slaughter for FDA-approved implants. Therefore it is most important that all implants be placed at the middle of the ear, beneath the loose skin overlying the conchal cartilage. This area is traditionally discarded at slaughter.

Pasture-Stocker Calves. Scientific studies indicate that growth promotant implants usually increase weight gain significantly over nonimplanted animals, in some cases up to 30 lb (14 kg) or more/implant. Genetics, nutrition, and implant program planning are key factors. If the animals are not consuming adequate nutrients above maintenance requirements, the response to implanting will be negligible. The producer should match nutrition and the selection of the appropriate implant to the length of the grazing period in order to achieve maximum growth promotion. The use of implants on pasture-stocker calves may affect (reduce) response to subsequent implants, as well as marbling at slaughter, if the nutrition and implant program are not planned correctly.

Feedlot Steers and Heifers. The proper use of growth promotant implants in feedlot steers has led to improvements in rates of gain up to 30% and feed conversion up to 17% compared with nonimplanted controls, thereby consistently returning $7 to $10/dollar spent/implant period. An understanding of the implant's ingredients, levels, payout period, and impact on performance must be attained, and strategies for appropriate use developed. The first objective is to determine days on feed (DOF). Including projections of DOF in implant considerations requires a paradigm shift or change in rational thinking. Historically, producers have administered estrogen implants at 70- to 100-day intervals after arrival, disregarding the relationship to slaughter date. By projecting DOF initially, the finished animal is the end product and thus becomes the focus of the program. The implants and implant strategy become a tool to influence performance and carcass quality.

Implants influence rate of gain and feed conversion by increasing protein accretion (muscle). They may delay, interrupt, or not affect the actual amount of marbling (fat) deposited. Therefore the producer must set goals for performance, quality grade, or a combination of the performance and quality grade achievable when planning the implant program. The current USDA grading system is a "visual" system, in which the grader is comparing the ratio of muscle to fat. Increases in muscle tissue deposition may change the ratio enough to drop the quality grade. Recent research indicates that possible negative effects on marbling may be minimized if a step-up program in implant dose-effect is used: (1) low dose to higher dose (suckling calf to slaughter), (2) not overlapping one implant effective period on the next, at least not within the first half of the previous implant's estimated effective period, and (3) not exceeding the level of hormone to which the animal can respond in any given growth phase.

The producer should match nutrition and the selection of the appropriate implant(s) to the length of the feeding period, performance goals, and desired carcass parameters.

Descriptions of implants and their use can be found elsewhere (Botts et al, 1997). Box 14-7 shows a list of current approved growth implants.

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BOX 14-7

Currently Approved Growth Implants

SYNOVEX C, IMPLUS C, COMPONENT E-C
These implants contain 10 mg estradiol benzoate (72% estradiol) and 100 mg of progesterone. They are recommended for use in suckling beef calves weighing up to approximately 400 lb (182 kg). Synovex C may be used in both steer and heifer calves, including one-time use in beef heifers intended for later breeding.*

REVALOR-G
Revalor-G contains 40 mg trenbolone acetate (synthetic androgen) and 8 mg of estradiol in a slow-release delivery system that increases rate of weight gain in pasture cattle (slaughter, stocker, and feeder steers and heifers).

RALGRO
Zeranol, the active drug in Ralgro, is a chemical derivative of resorcylic acid lactone fermentation product, with estrogenic properties. Ralgro contains 36 mg of zeranol and is used to increase the rate of weight gain and improve feed conservation in growing cattle, feedlot heifers and steers, and weaned and suckling calves. Ralgro has been approved for one-time use in beef heifers intended for later breeding.

RALGRO MAGNUM
Ralgro Magnum contains twice the active compound, zeranol (72 mg), as Ralgro. Magnum is used to increase rate of weight gain in steers fed in confinement for slaughter. Because of the increase in zeranol level, Magnum is reported to have a longer growth-promoting effect than Ralgro.

SYNOVEX S, IMPLUS S, COMPONENT E-S
These implants contain 20 mg estradiol benzoate (72% estradiol) and 200 mg of progesterone. They are recommended for use in steers weighing 400 lb (182 kg) or more. When the implants are properly administered, they can help increase rate of weight gain and improve feed efficiency.

SYNOVEX H, IMPLUS H, COMPONENT E-H
These implants contain 20 mg estradiol benzoate (72% estradiol) and 200 mg of testosterone propionate. Synovex H is recommended for use in heifers weighing 400 lb or more. When the implants are properly administered, they can help increase rate of weight gain and improve feed efficiency.

COMPUDOSE 200
Compudose 200 is a silicone rubber implant containing 25.7 mg of estradiol and coated with not less than 0.5 mg of oxytetracycline powder as a local antibacterial. Compudose 200 is intended for increased rate of weight gain in suckling and pastured growing steers, and improved feed efficiency and increased rate of weight gain in confined steers and heifers.

ENCORE
Encore is a silicone rubber implant containing 43.9 mg of estradiol, with a similar coating and animal approval to Compudose 200. It is reported to have a longer growth-promoting effect than Compudose 200.

FINAPLIX-H
Finaplix-H contains 200 mg of a synthetic androgen, trenbolone acetate. Trenbolone acetate has been shown to have 8-10 times the growth promoting ability of an equal amount of testosterone. Finaplix-H increases the rate of weight gain and improves feed efficiency in growing finishing heifers.

REVALOR-H
Revalor-H contains both estradiol (14 mg) and trenbolone acetate (140 mg) for increased rate of weight gain and improved feed efficiency in a slow-release delivery system in heifers.

SYNOVEX PLUS
Synovex Plus contains 28 mg of estradiol benzoate (72% estradiol) and 200 mg of trenbolone acetate. Synovex Plus is recommended for improved feed efficiency in steers and heifers fed in confinement for slaughter.

REVALOR-S
Revalor-S contains both estradiol (24 mg) and trenbolone acetate (120 mg), which increases rate of weight gain and improves feed efficiency in a slow-release delivery system in steers.*

*Generic equivalents, approved by the Food and Drug Administration, are available from Ivy Labs/Vet Life (Component) and the Upjohn Company (Implus).

Growth-Promoting Feed Additives. Several growth-promoting feed additives are available for incorporation into feedlot rations. The economic advantages include improved average live weight gains, improved feed efficiency, and, in some cases, control of certain diseases.

Ionophores. Carboxylic polyether ionophore antibiotics, also known as ionophores, cause an increase in the molar proportion of propionic acid and a concomitant decline in the molar proportion of acetate and butyrate in the volatile fatty acids produced in the rumen (Bergen and Bates, 1984). Monensin has been used most extensively, but other agents, including lasalocid and laidlomycin, have been investigated or are used commercially (Russell and Strobel, 1989). Monensin's mode of action and influence on the performance of cattle have been reviewed by Schelling (1984) and Goodrich et al (1984). Monensin sodium may be used from the beginning of the feeding period until slaughter (Burrin et al, 1988). It improves feed efficiency by about 10% and, when used during the first 28 days of the feeding period, assists in the control of coccidiosis. Lasalocid is also widely used as an ionophore (McCutcheon, 1989).

Tylosin at levels of 60 to 90 mg/head/day is used in the feedlot for the prevention of liver abscesses and can be used along with monensin. Chlortetracycline and oxytetracycline

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at levels of 10 g/ton of feed may be given to feedlot cattle as growth promotants in some countries. Feeding of chlortetracycline at a subtherapeutic level can benefit nonstressed cattle in a feedlot situation, and responses can be equal to or greater than those observed with monensin or lasalocid (Beacom et al, 1988). The body tissues (muscle, liver, kidney) of animals fed chlortetracycline contained no repeatable detectable residues of the antibiotic. Thus if antibiotics are properly fed and the proper withdrawal period is used, there should not be a residue problem. The development of drug-resistant strains of bacteria in cattle fed the drug for long periods is of concern and must be monitored. The effects of monensin and chlortetracycline in high-concentrate and high-forage diets for implanted and nonimplanted finishing steers and heifers have been compared by Beacom and Mir (1985).

Vitamin Injections. Vitamin injections are used in some processing schedules as a mixture of vitamins A, D, and E. This procedure prevents any possible occurrence of hypovitaminosis A, which may be present in cattle that have originated from a dry carotene-deficient pasture or diet. However, the vitamins may also be supplied in the feed at high concentrations during the conditioning period to increase levels in the liver.

BEEF QUALITY ASSURANCE AND BEEF SAFETY PROGRAMS

The purpose of the beef quality assurance (BQA) program is to identify and avoid areas in the feedlot where quality or safety defects can occur. Feedlots seek all sources of information needed to accomplish BQA goals and objectives. The BQA program is a cooperative effort between beef producers, veterinarians, nutritionists, extension staff, and other professionals. The program encourages everyone involved with beef production to follow the government guidelines for product use and to use common sense, reasonable management skills, and accepted scientific knowledge to avoid product defects at the consumer level. The goal of the BQA program is to assure the consumer that all cattle shipped from a feedlot are healthy, wholesome, and safe and that their management has met all government and industry standards.

The BQA objectives for the feedlot should be as follows:

1. Set production standards for the feedlot that can be met or exceeded.
2. Establish systems for data retention and record keeping. Record-keeping systems that meet government and industry guidelines allow validation of management activities and fulfill the program goal.
3. Provide hands-on training and education for all personnel to meet or exceed the guidelines of the BQA program and to realize the benefits of such program.
4. Use technical assistance available through cattlemen associations, the veterinarian, the nutritionist, and university staff. The feedlot veterinarian should serve as the facilitator of the BQA program for the feedlot.

Quality Challenges

The importance of BQA is obvious when the top eight quality challenges within the beef industry are analyzed. These quality challenges include injection site blemishes, rib brands, excessive external fat, excessive seam fat, dark cutters, inconsistent size of meat cuts, inconsistent cuts, and nonuniform cattle. The primary beef safety concerns are antimicrobial resistance and violative chemical residues.

According to the 1995 National Beef Quality Audit (NBQA), injection site blemishes cost the beef industry $188 million annually, or an average of $7.05/animal. Brands and other hide defects, such as parasite damage, cost the beef industry more than $648 million annually. Typically, these losses are passed to cattle producers by a reduction in live cattle price, or "built-in discounts." This is equivalent to $24.30/head.

The BQA challenge to improve beef quality includes the following: eliminate side and multiple brands, remove horns, improve parasite control, improve red meat yield, improve handling-transport techniques, eliminate IM injections, measure traits that impact value, and eliminate genetic and management systems that negatively affect tenderness, juiciness, and flavor.

History of Beef Quality Assurance in the United States

Consumers demand safe food. Because of concerns with additional government regulation and potential loss of modern production tools, in 1980 cattlemen began investigating ways to ensure that their production practices were safe and would satisfy the concerns of the consumer.

In 1982 the USDA-Food Safety Inspection Service (USDA-FSIS) began working with the beef industry in the United States to develop the Pre-Harvest Beef Safety Production Program. To side-step additional governmental regulatory programs, the beef industry developed the BQA program, a self-regulating program that became an important key for avoiding additional government regulation. Currently 47 states and more than 90 percent of the United States beef production are involved with the voluntary program. Industry self-regulation has proven very successful and will continue to allow industry the flexibility needed to produce safe and wholesome food in an economical manner. Success of the effort is clear; violative chemical residues have nearly disappeared in fed beef cattle, and injection site lesions have been reduced by over 67 percent.

While the BQA program was developing, the Pillsbury Company was implementing a quality control program for the space industry that used many of the same principles. Their program, hazard analysis of critical control points (HACCP), gained universal acceptance and is presently the dominant outline for quality assurance programs in processed foods. Because of USDA regulation, all U.S. packing plants have developed, or will be developing in the near future, HACCP programs.

The HACCP concepts are the same as those of BQA. It is a process of determining what could go wrong, planning to avoid it, and documenting what was done, with the additional step of validation. USDA's HACCP program for the packing industry includes foodborne bacterial pathogen control, a problem that currently is not controllable at the farm, ranch, or feedlot level. When preharvest bacterial pathogen control measures become available or government regulations mandate control measures, the valuable experience working with the present BQA programs will help producers adapt to any new requirements.

Important Points for Beef Quality Assurance to be Successful (Box 14-8)

The feedlot veterinarian, feedlot management, and staff cannot foresee all potential problems. They must identify one area at a time, then develop and implement a plan for ensuring quality in that area of production. The experience gained will make it easier to develop quality assurance in other areas of the operation.

Violative residues and product-related defects can be avoided if animal health products are administered according to government and industry standards and if BQA

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BOX 14-8

Beef Quality Assurance Guidelines and Agreements

FEEDSTUFFS AND SOURCES

- The feedlot must maintain a record of pesticide (herbicides, insecticides, etc.) use that could cause a violative residue in feedlot cattle. Governmental regulations describe what records must be kept.
- The feedlot must maintain a quality control program for incoming feed ingredients. Every effort must be made to eliminate contamination resulting from molds, mycotoxins, and chemical contamination, such as pesticides.
- Submit any feed ingredient suspected of contamination for analysis by a qualified laboratory before use.
- Certain ruminant-derived protein sources, such as meat and bone meal, cannot be fed. Other ruminant-derived products, such as blood by-products and tallow, can be used in feedlot diets.

FEED ADDITIVES AND MEDICATIONS

- Only government-approved medicated feed additives can be used in rations.
- All medicated feed additives should be used in accordance with the approved label. Extra-label use of feed additives is strictly prohibited in the United States; however, Canadian law allows for extra-label usage of feed additives when prescribed by a veterinarian.
- The feedlot should ensure that all additives are withdrawn at the proper time to avoid violative residues.
- Medicated feed additives should be used in accordance with good manufacturing practices (GMPs). These include a formula record of all medicated feed rations produced and production records of all batches of feed produced that contain medicated feed additives. Production records must include additive used, date run, ration name or number, and amount produced.
- The feedlot should keep all records for at least 2 years from the date of transfer or sale of the cattle and have the capability of trace-back.

ANIMAL HEALTH PRODUCTS AND INJECTIONS

- Follow all governmental guidelines for product usage.
- All products labeled for subcutaneous (SQ) use must be administered as such in front of the shoulders.
- All products labeled for IM (intramuscular) use must be administered only in the neck region. No injections should be given in locations other than the neck, regardless of calf age.
- Products that cause excessive tissue damage should be avoided whenever possible.
- Products approved for SQ, IV, and oral administration are preferred over those labeled for IM usage.
- Products with low-dose volume are preferred, and proper spacing of injections should be practiced.
- Products should not be administered at more than 10 ml/site unless otherwise stated on the label.
- Aminoglycosides should not be used extra-label because of unknown or unpredictable preslaughter withdrawal time.

ANIMAL HEALTH TREATMENT AND PRODUCT USE RECORDS

- Treatment regimens should follow label directions unless the feedlot veterinarian has determined the need to use a product extra-label.
- Extra-label drug use shall be used only when prescribed by the feedlot veterinarian.
- All cattle treated with medications administered extra-label must comply with prescribed, extended withdrawal times that have been set by the feedlot veterinarian under the guidelines of a valid veterinarian-client-patient relationship (VCPR). The Food Animal Residue Avoidance Databank (FARAD) is the primary resource for determining the preslaughter withdrawal time when an animal has been treated extra-label.

Individual Treatments

- Treatment records should be maintained for all cattle treated individually. This can be done using hand generated records or using a computerized record system. Essential information includes the individual animal identification, treatment date(s), diagnosis, drug administered, serial-lot number, dosage used, approximate weight of animal, route and location of administration, and earliest date the animal could clear the preslaughter withdrawal period.

record-keeping standards are maintained. A number of safeguards built into the beef-feeding system help avoid quality defects. These include handling of animals on an individual basis, length of time required to produce a finished product, and quality and safety built into modern health related technologies of beef production. Every employee must be trained to know, understand, and identify areas where possible quality defects or contamination with violative residues can occur. Suppliers of services, commodities, or products must understand the feedlot's quality assurance objectives.

The feedlot must be able to document all the steps of production. Good production records also allow for documentation, analysis, and improved financial decisions. There are points in production that must be monitored to ensure no residue violations or carcass defects occur. The critical points include, but are not limited to, incoming cattle, products and commodities, cattle handling, and evaluation of outgoing cattle. Some production areas that have higher residue and carcass defect risks than others. High-risk production areas include nonperforming cattle, unusual single source feed ingredients, and suppliers of nonstandard supplies (Smith et al, 1997).

Beef Quality Assurance Good Management Practices

Feedstuffs and Commodity Sources

Monitoring Feedstuffs. It is essential to monitor feed sources. Feedlots purchasing outside feeds should maintain a sampling program to test for quality specifications of feed-

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BOX 14-8 —cont'd

Group Processing or Mass Treatments

- All animals treated as part of a group (processing or mass medication) should be group or lot identified, and the treatment information should be recorded. Records should include the animal lot or group identification, product used, serial-lot number of the product, date treated, dosage used, route and location of administration, and withdrawal information. A preslaughter withdrawal time is assigned to the entire pen. Recording treatments under this system assumes that every animal in the lot or group received the treatment.
- The health records of cattle shipped to slaughter should be checked by feedlot personnel to ensure that treated animals have cleared the appropriate withdrawal times.
- A release slip should be signed and dated by the person who checks the records before the animals are released from the feedlot.
- The treatment history of cattle with chronic medical problems or those that have a poor, unexplained growth rate, should be scrutinized carefully. In many cases residue screening, such as the live animal swab test (LAST), is advisable. Residue screening should be performed under the supervision of the feedlot veterinarian. The results of such testing determine whether an animal can be released for shipment but cannot be used to shorten the labeled withdrawal time.
- All pesticides should be used in accordance with label directions. Record all pesticide use such as pour-ons or injectables, including product identification, lot-serial number, date used, amount used, and withdrawal time.

RECORD KEEPING

- All records should be kept for at least 2 years after cattle have been shipped from the feedlot.
- All BQA-related records should be inspected periodically by the veterinarian providing consultation service to the feedlot.
- If a violative residue is found in any cattle shipped for slaughter, the feedlot must make applicable records available to the appropriate government agencies. The source and cause of the violative residue should be determined and corrective action taken to prevent reoccurrence.
- Records can be kept on a computer or in written form, as long as they meet the aforementioned specifications and allow for verification of actions taken.

CARCASS QUALITY

- The feedlot should strive to prevent bruising during animal handling. When possible, bruising rates should be monitored at the packing plant.

stuffs, such as moisture, protein, and foreign material. Suppliers should be informed that sampling of delivered products will occur. A good business practice is to require all products to be accompanied by an invoice, which includes the date, amount, and signatures of both the person who delivered the product and the person who received the product. Grain suppliers should understand that protectants can have withdrawal times. Most bonded, reputable suppliers have a quality control testing program of their own, including polychlorinated biphenyls, chlorinated hydrocarbons, organophosphates, pesticides and herbicides, heavy metals, and microbes (*Salmonella*). As part of the BQA program, the feedlot should ask for the test results.

A quality control program for feedstuffs helps prevent chemical residues and ensures high-quality feeds. Visual inspection of feeds can avoid some problems. A checklist—including such items as color (typical, bright, and uniform), odor (clean and characteristic), moisture (free flowing, no wet spots, and moisture testing), temperature (no evidence of heating), no evidence of foreign material, and evidence of bird, rodent, or insect contamination—can serve as a tool to accept or reject a load of commodities or feed.

It is neither efficient nor economically feasible to test every load of grain or forage for contaminants. A logical alternative is to take a representative sample of each batch of newly purchased feed and store it in case a feed-related problem occurs in the future. Commonly, a thorough investigation of suspected feed-related problems is not possible because no representative sample is available for testing. If feed sampling and storage is done on a routine basis and a suspected feed-related problem occurs, samples for appropriate laboratory testing will be available. A recommended sampling method for purchased grains, supplements, or complete feeds is to randomly sample each batch of feed in five to ten locations and pool the individual samples into a larger sample of 2 to 5 lb (0.9 to 2.3 kg). The pooled sample should be placed in a paper bag or small cardboard box, labeled and frozen. Dry samples can be labeled and kept in a dry area. Higher moisture samples should be frozen. A feed tag should be attached to the sample if needed for future reference.

Forage samples should also be collected and stored. If multiple bales of hay are purchased, representative samples should be obtained from several bales and mixed together before storage. Core samples are preferred over "grab" samples, particularly from large bales of hay. Most hay samples can be stored in a labeled paper bag and kept in a clean, dry area.

High-Risk Feeds. High-risk feeds are single loads or batches fed to cattle over a prolonged period, thereby exposing large numbers of cattle. Examples include fats, rendered by-products, plant by-products, supplements, and additives. Typically, these feedstuffs are only a small percent of the total diet and are very expensive to test. Suppliers should understand the feedlot BQA concerns and should provide quality specifications with the product. It is best to do business with a bonded supplier.

Ruminant By-Products. Because of bovine spongiform encephalopathy concerns, certain ruminant-derived protein sources, such as meat and bone meal, cannot be fed. Ruminant-derived products such as tallow and blood by-products are acceptable under the BQA program. Pure porcine

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and equine meat and bone meals can also be fed to feedlot cattle.

Potential Feed Toxins. It is important that feedlot managers and staff have some knowledge about the relative toxicities of chemicals to livestock so that highly toxic chemicals, such as soil insecticides, will be handled and stored properly. All chemicals should be treated as potential hazards and should be stored away from feed storage and mixing areas. If a feed-related poisoning is suspected, it is critical for the feedlot veterinarian to contact a diagnostic laboratory for assistance in confirming the suspicion. Some poisoning incidents may be reportable to the appropriate federal or state-provincial government agencies.

Naturally occurring mycotoxins also pose a threat to quality beef production in the feedlot. Mycotoxins can be found in grains and forages and, if present in sufficient concentrations, can cause reduced feed consumption, poor production, and adverse health effects. Mycotoxins can be produced in feedstuffs before harvesting or during storage. More commonly found mycotoxins include aflatoxin, vomitoxin, zearalenone and fumonisins in grain, primarily corn, and slaframine in red clover. Ergot alkaloids can be found in either grain or grass hays.

Fats. Steps should be taken to ensure that purchased fats and oils do not contain a residue. Discuss the quality of product with suppliers and request information about the sources, quality, stability, and consistency of the product. Feedlots may be approached by brokers who offer a cheaper source of feed grade fats; however, the potential for contamination increases with cheaper sources of fats.

Reputable dealers should be testing fats for such contaminants as polychlorinated biphenyls, chlorinated hydrocarbons, pesticides, heavy metals, *Salmonella*, and tall oil (hydrocarbon). Verification of testing should accompany the product.

Good Management Practices

Good management practices (GMPs) include feed handling facilities designed to reduce the risk of feed contamination with chemicals, foreign materials and disease-causing infectious agents. All chemicals (pesticides, lubricants, solvents, medications, etc.) should be stored away from feed supplies. Feed-handling equipment should be checked routinely for fluid leaks. Feedstuffs should not be stored around electrical transformers. Dual-purpose equipment, such as loaders (including shovels) that may handle feed and other materials (such as manure or dead animal removal), should be cleaned thoroughly before feed is handled. No vehicles other than feed-handling equipment should be allowed into feed storage areas, such as silage pits. The most common source of infectious agent contamination comes from animal or human feces. Feedstuffs, feed troughs, and water supplies should be protected from contamination with chemicals, foreign material, and feces. Control of rodents, birds, and other wildlife is important to avoid fecal contamination with many common infectious agents.

Animal Treatments and Health Maintenance

Management

Feedlots have done an excellent job of minimizing violative drug residues. This has been accomplished by placing emphasis on the identification of treated cattle and good record keeping. This includes identifying each animal treated; accurately recording the product(s) used, treatment date, and treatment dosage; and following prescribed withdrawal times.

Treatment Protocol Book

The feedlot veterinarian should provide a Treatment Protocol Book specific to the feedlot operation. The Treatment Protocol Book should be reviewed regularly and updated at least every 90 days. One copy of the Treatment Protocol Book should be kept at the treatment facility and another copy should be maintained in the feedlot office. A written treatment protocol, along with current prescriptions (purchase orders), are important documents that the feedlot must have if there is a government inspection of the feedlot facilities, drug usage procedures, and residue avoidance plans. Of greater significance, the treatment book provides written guidelines for animal health programs, thus minimizing chances of mistakes or misunderstandings.

Injections

A critical part of a feedlot BQA program is the proper administration of animal health products. All injections should be given in front of the shoulders—never in the rump or back leg. When possible, IM injections should be

TABLE 14-4

Guidelines for Needle Selection for Feedlot Cattle

	Route of Administration								
	Subcutaneous injection ($\frac{1}{2}$- to $\frac{3}{4}$-in needle) (cattle weight, lb)			Intravenous injection ($1\frac{1}{2}$-in needle) (cattle weight, lb)			Intramuscular injection (1 to $1\frac{1}{2}$-in needle) (cattle weight, lb)		
INJECTABLE VISCOSITY	<300	300-700	>700	<300	300-700	>700	<300	300-700	>700
Thin (e.g., virus vaccine)	18 gauge	18-16 gauge	16 gauge	18-16 gauge	16 gauge	16-14 gauge	20-18 gauge	18-16 gauge	18-16 gauge
Thick (e.g., oxytetracycline)	18-16 gauge	18-16 gauge	16 gauge	16 gauge	16-14 gauge	16-14 gauge	18 gauge	16 gauge	16 gauge

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avoided. However, some animal health products are labeled for IM use only. If IM medications must be used, they should be administered in the neck at a maximum of 10 ml/injection site. As a general rule, feedlot personnel should not inject more than 10 ml subcutaneously in each injection site; however, some products are labeled for use up to 20 ml/injection site.

Bent and Broken Needles

The veterinarian should educate all feedlot personnel on proper cattle handling, cattle restraint, and proper injection technique. Improper animal restraint is the cause of most bent needle problems. If a needle bends, it should never be straightened and reused. Although rare, a needle can break off in the muscle. A broken needle is an emergency, and time will be of the essence. Broken needles migrate in tissue and if not handled immediately will be impossible to find, requiring the animal to be destroyed. Under no circumstances should animals with broken needles in them be sent to market. The veterinarian should outline procedures for handling such cases in the Treatment Protocol Book. Purchase of high quality needles, changing and discarding of damaged needles, and proper restraint are all preventative measures. Guidelines for needle selection are found in Table 14-4.

PUTTING BEEF QUALITY ASSURANCE TO WORK THROUGH THE HAZARD ANALYSIS CRITICAL CONTROL POINT SYSTEM

"Build on what you know" is the operative phrase in any BQA program. The BQA program road map is the HACCP system. The veterinarian, nutritionist, feedlot management and staff, and other specialists must look for what could go wrong, then determine ways to avoid the problem. A system must be developed to check, verify, and document what has been accomplished. Everyday working techniques must be designed to avoid problems, especially those problems that can cause a safety or quality defect. This includes evaluation of safety hazards that can affect employees (Boxes 14-9 and 14-10 and Figs. 14-10 and 14-11).

Examples of HACCP outlines for feed and product use are shown in Figs. 14-12 and 14-13. The concept of BQA is as simple as considering what can go wrong in production that could cause a quality defect and figuring out how to prevent it from going wrong. The veterinarian cannot monitor what he or she does not measure, so it is important to document and verify the steps taken to avoid having problems occur.

DEVELOPMENT OF ANTIMICROBIAL-RESISTANT BACTERIA

A comprehensive review of the use of antimicrobials in beef cattle health management and the relationship to antimicrobial resistance was published recently (Radostits, 1999). The use of antimicrobials, particularly the subtherapeutic use of antimicrobials, in the feed of feedlot cattle is controversial because it may promote the development of antimicrobial-resistant strains of bacteria. The major concern is that these strains can then be transferred in the meat to humans, causing disease that may be difficult to treat because of drug resistance. It is also possible that resistance plasmids from animal enteropathogens can be transferred by the process of conjugation to human enteropathogens.

The bacteria of major concern in this context are *Campylobacter* and the *Salmonella* spp., which occur commonly in the intestinal tract of animals and are known as enteric bacteria. The use of subtherapeutic levels of antimicrobials in the feed of cattle can result in the emergence of drug-resistant strains of bacteria in the intestinal flora of the animals. The resistance may be to several antibiotics, a phenomenon known as multiple-drug resistance. If these bacteria contaminate beef carcasses, they can become a foodborne pathogen for humans who handle the meat or eat meat that is not cooked adequately.

In the mid-1960s in England, a single antibiotic strain of *Salmonella typhimurium*, phage type 29, caused an extensive outbreak of disease in cattle. Salmonellosis also occurred in some farm personnel. Antimicrobials had been used prophylactically and therapeutically to treat sick cattle, and it

BOX 14-9

Hazard Analysis Critical Control Points (HACCP): Five Preliminary Steps

ASSEMBLE THE FEEDLOT HACCP TEAM: BRING TOGETHER THE HACCP RESOURCES

Everyone involved, including the veterinarian, the nutritionist, extension and university specialists, suppliers, and employees, should help identify production areas where quality problems and defects could occur. The team should review the final HACCP plan to ensure that it is comprehensive and workable.

DESCRIBE THE PRODUCTION SYSTEM AND HOW THE CATTLE ARE MANAGED

Each feedlot will have some differences in its HACCP system. There is a built-in margin of safety for withdrawal times in the feedlot industry, since most withdrawal times for animal health products are shorter than the feeding periods. Feedlot personnel must be aware of high residue-risk situations. Nonperforming cattle (e.g., chronics) could have organ damage, which could prevent normal clearance of a product, causing violative drug residues even after the preslaughter withdrawal time has elapsed.

IDENTIFY WHO BUYS THE CATTLE AND COMMUNICATE WITH THEM

Most feedlots sell cattle directly to packers. There is no room for error in preslaughter withdrawal times or physical injury that causes bruising. The packer should immediately notify the feedlot of any quality or safety defects so that they can be corrected quickly.

DEVELOP AND VERIFY A PROCESS FLOW DIAGRAM

Outline all of the steps of production. The members of the HACCP team should evaluate each step for the potential causes of quality or safety defects. The defects include (1) bacterial contamination, which can cause infectious disease in cattle or employees, (2) chemical usage-contamination, which can lead to violative residues, and (3) physical damage such as injection site damage, bruising, or broken needles in animal tissue.

MEET THE REQUIREMENTS FOR THE BEEF QUALITY ASSURANCE GOOD MANAGEMENT PRACTICES AND STANDARD OPERATING PROCEDURES (SOPs)

Include sanitation SOP (finding ways to prevent or minimize fecal-oral contamination).

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BOX 14-10

Seven Specific Hazard Analysis Critical Control Points (HACCP) Steps

IDENTIFY POTENTIAL PROBLEMS OR HAZARDS: BACTERIAL, CHEMICAL, AND PHYSICAL (B-C-P)

Conduct a production analysis to identify potential problems that could occur in the production process. The use of a production flow diagram provides the best guide to ensure no area has been overlooked.

IDENTIFY CRITICAL MANAGEMENT POINTS OR CRITICAL CONTROL POINTS (CCPs)

CCP must be identified in the production process at which potential problems could occur and be prevented or controlled. The use of the production flow diagram-outline-list provides the best guide for identifying where potential problems might occur and points at which training-management activities may reduce or eliminate the hazard.

ESTABLISH CRITICAL LIMITS (CLs) FOR CCPs

Limits must be established for preventive measures associated with each critical management point. Determine how to identify when a production activity is not being conducted properly. Some limits are easy to establish and some are not. For example, giving all injections in the neck is a CCP. Any injection not given in the neck is outside the CL. Providing clean water for cattle to drink might be a CCP, but within minutes of cleaning a water trough, recontamination of the water (outside CL) can occur. The best possible method is to follow a reasonable cleaning schedule. Proper handling of cattle (another CCP) is important, but establishing a well-defined CL is difficult.

ESTABLISH CCP MONITORING PROCEDURES

Each CCP must be monitored to ensure it stays within the established limits set by management. Supervision on a timely basis is the key. This step outlines a person(s) in the feedlot who is designated to regularly check to ensure the activity is being carried out in a manner that meets the feedlot's (management's) objective (the CCP). Simply stated, is anyone checking to make sure that activities are being done like they were intended, or as best as possible under the circumstances? A scheduled checklist is useful. The CCP monitoring list will help employees to keep from overlooking important items. A feedlot's CCP monitoring list may have items scheduled for checks on a daily, weekly, monthly, or yearly basis. Examples of beef quality assurance checklists are shown in Figs. 14-10 and 14-11.

ESTABLISH CORRECTIVE ACTIONS (CAs)

CA must be taken when monitoring determines a critical management point is not within established critical limits. CA should include what will be done in the future to prevent the problem from happening again. "What do you do if ..." needs to be discussed and decided before something goes wrong. There are two reasons it is important to establish CA before a problem occurrs: The problem will be corrected faster, and the CA needed may change the seriousness of the problem. Understanding the seriousness of potential problems may change how prevention of the problem is viewed by employees. The HACCP team should help develop possible and appropriate CAs.

ESTABLISH VERIFICATION PROCEDURES

Testing and other measurements must be used to verify the program is working properly. For example, liver abscess reports from a packer are appropriate for verifying that a feedlot's liver abscess control program is working.

ESTABLISH RECORD-KEEPING PROCEDURES

Keep records that document the management system is being monitored and is working correctly. Any records system will work as long as it is appropriate to meet the needs of the HACCP system developed for the feedlot.

was thought that this use may have been responsible for the proliferation and dissemination of the strain. Subtherapeutic levels of drugs had not been used.

After this outbreak, the British Minister of Agriculture, Fisheries and Food and the Minister of Health appointed a Joint Committee on the Use of Antibiotics in Animal Husbandry and Veterinary Medicine. The committee, chaired by Dr. M. Swann, was asked to collate the available information on the use of antimicrobials in animal husbandry and to determine its impact on animal and human health.

In 1969 the Swann Report concluded that the administration of antimicrobials to farm livestock, particularly at subtherapeutic levels, posed certain hazards to animal and human health. These hazards included an increase in the resistance of enteric bacteria of animal origin to one or more antibiotics; the ingestion by humans of antibiotic-resistant salmonellae, possibly endangering life; the presence of antibiotic residues in animal products, which could induce harmful effects such as allergic reactions or toxicities; and the fact that certain bacteria such as *Salmonella typhi* might acquire resistance to chloramphenicol, which at that time was considered to be the most effective antibiotic for the treatment of typhoid fever.

After the release of the report, antibiotics were officially classified into two categories in England. The first consisted of agents approved for use in animal feeds as growth promotants; these included bacitracin, virginiamycin, and bambermycins. The second consisted of antimicrobials that were used as therapeutic agents in human or animal medicine such as penicillin and the tetracyclines. These were banned for use in the feeds of animals unless prescribed by a veterinarian. Later, unrestricted sale of the macrolide antibiotic tylosin for growth-promoting purposes was allowed, and this agent was retained as a prescription antibiotic for therapeutic purposes in animals. The results of large-scale surveys have indicated that, in general, antibiotic resistance in bacteria has not increased, especially in Europe and North America (Walton, 1988).

In summary, the United Kingdom's experience in restricting the use of antibiotics in feeds has shown that resistance in bacteria probably develops in spite of the controls on subtherapeutic concentrations of "feed" antibiotics not used

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Beef Operation _____ Date _____ Evaluator _____

Feeding Facilities
Feed storage inspected for contamination before receiving new loads of ingredients.
Feed storage area only used to store feed ingredients (no pesticides, solvents, etc.).
Water source protected and checked yearly for contamination.
Procedures in place to protect feed-handling equipment contamination.
All feed-handling equipment checked for contamination before each use.

Receiving Feedstuffs
Receiving Log Record: source (verified), date, description.
Training.
Basic Quality Control:
1. As needed for economic evaluation of feedstuff (e.g., moisture, protein).
2. Visual inspection for contaminants (e.g., pink seed corn).
3. Source-verify high oil feeds (e.g., fat from packing plants versus blended fats).
4. Inspect trucks for contaminants (e.g., any signs of hauling dangerous materials before feed).
5. Samples of "high-risk" feeds stored as per nutritionist recommendations.

Feed Additives
Receiving Log Record: source (verified), date, description (including serial-lot no.).
Stored separate from other feedstuffs.
Use Log Record: date, dose per ton, ID of animals.
Physical Inventory Log (can be column in use log).
Training for using feed additives.

Feed Formulas
Record of all feed formulas.
Medicated feed formulas checked by nutritionist or veterinarian for accurate dosing.
Directions for use, including withdrawal.
Training.

Batch/Load
Batch Log.
Minimum/maximum and exception table or chart for ingredients and mixing.
Training.

Feed Delivery
Delivery Log/Load Tickets.
Delivery matches call.
Training.

Cattle Release
Withdrawal checked on all feed records.

FIG. 14-10 Example of a beef quality assurance feedlot feed check.

in humans. Thus prohibition of subtherapeutic doses of antibiotics in animals has not prevented or even affected the prevalence of resistant bacteria in the United Kingdom. It is also difficult to ascertain the effectiveness of the Swann Committee recommendations, because animal health and production practices have improved substantially and the therapeutic use of antibiotics may be a more important factor in the selection of resistant organisms than subtherapeutic use. Resistant strains of salmonellae and other bacteria have persisted; some have increased in incidence, and others have decreased. The reasons for the changes are unknown but do not appear to be related solely to the presence of antibiotics in the gastrointestinal tract.

One important factor confounds the study of the effects of subtherapeutic use of antimicrobials in animal feeds: a significant proportion of antimicrobial resistance in humans may be a direct result of the therapeutic use of antimicrobials in humans, not of antimicrobial use in agriculture. The use of effective antibiotics simply eliminates a large proportion of the sensitive organisms and allows resistant bacterial species to emerge. Similarly, antimicrobial resistance in veterinary medicine is usually the result of the therapeutic use of antimicrobials in animals. When the prevalence of resistance to any species of bacteria increases, it is usually associated with the introduction of a new antimicrobial, whether in human or veterinary clinical practice.

In 1980 the National Academy of Sciences commissioned the Committee to Study the Human Health Effects of Subtherapeutic Antibiotic Use in Animal Feeds (National

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Beef Operation _____ Date _____ Evaluator _____

Cattle Handling Facilities
Inspected for proper function for cattle and human safety before each use.
Handling facilities and equipment properly designed, maintained, and used.

Receiving Cattle
Appropriate Health/Import/Transfer/Movement Records.
Cattle Handling Training.
Basic Quality Control.
Holding pens and handling alleys properly designed and maintained.
Clean feed and water as needed.
Receiving Log Record: source (verified), date, description.

Processing, Health Management, Mass Medication, and Pesticide Products (Receiving, Storage, and Use)
Receiving/Inventory Log/Record: source (verified), date, description (name, serial-lot no.).
Stored in protected area: refrigerated as needed, sunlight controlled, locked if required.
Use (Processing/Treatment) Records for all cattle: date, animal(s) ID, diagnosis/reason, product, dose, withdrawal, and release date.
Processing Maps used for processing cattle (includes product and serial-lot no.).
Minimum/maximum and exception table or chart for product use.
Product Handling and Use Training (including MSDS, product inserts, etc.).
All injections should be given in the neck region, injectables given Sub Q if possible.
Supplier Agreements and Veterinary Drug Order (as appropriate).
Signed Use Protocols (Processing, Treatment, Premise Pesticides).
Follow FDA/USDA/EPA guidelines for all product use.
Equipment for delivery properly designed, maintained, and used.
Cattle: chutes, snakes, holding pens, syringes, needles.
Feed and Pesticides: scales, mixers, delivery system.
Proper disposal of used containers.
Withdrawal time established and estimated date for release (for injectables, see above).
Residue screening of nonperformers.
Training for processing, health management, mass medication, and pesticide products.

Feed Management
Withdrawal time established, release date estimated.
Feed management, mixing, and delivery training.
Follow FDA/USDA/EPA guidelines for all product use.
Training for feed management.

Cattle Release
Withdrawal checked on product used (Processing, Mass Med, and Treatment Records).
All withdrawal times met and LAST test all nonperformers.
Release/Transfer form signed by each department.

FIG. 14-11 Example of a beef quality assurance feedlot product use checklist. *FDA/USDA/EPA*, Food and Drug Administration/U.S. Department of Agriculture/Environmental Protection Agency; *MSDS*, material safety data sheet.

Research Council, 1980). After reviewing the evidence, the committee concluded that "the postulated hazards to human health from the subtherapeutic use of antimicrobials in animal feeds were neither proven nor disproven." The report went on to say that "the lack of data linking human illness with this subtherapeutic use must not be equated with proof that the proposed hazards do not exist." The research necessary to establish and measure a definite risk has not been conducted. The committee also concluded that it is not possible to conduct a feasible, comprehensive epidemiologic study of the effects on human health arising from the subtherapeutic use of antimicrobials in animal feeds, partly because it is impossible to determine the antimicrobial history of the animal from which a particular piece of meat came.

Some published reports in the medical literature claim that feeding of subtherapeutic levels of antibiotics to animals or therapeutically treating animals with various antibiotics results in an increase in the frequency of isolation of *Salmonella* spp. and E. *coli* organisms that are resistant to those antibiotics and that these bacteria can be transferred to humans and cause illness.

Holmberg et al (1984) reported on a human outbreak of infection with *Salmonella newport* resistant to ampicillin, carbenicillin, and tetracycline in several Midwestern states. Food histories and plasmid profiles of the organisms isolated from both affected humans and isolates from livestock in six states led the authors to conclude that the resistant organisms infecting the patients were of animal origin and that the probable source was contaminated

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The following table was reviewed with _____ (owner/manager)
To identify those areas appropriate to _____ (beef operation)
Min: Potential site of *minor* problem (s = safety, p = production, q = quality).
Maj Potential site of *major* problem (s = safety, p = production, q = quality).
CCP: Problem will exist if not controlled at this point (s = safety, p = production, q = quality).

BQA Hazard	CCP	Preventive Measures	Monitoring Procedures	Corrective Action	Records	Verification
Pasture maintenance pest/herb use	Min	Follow label directions	Observe Record Inspect	Keep cattle off until WD met	Pest/herb use records	Evaluate records
Raised feed	Min	Employee training Approved products Withdrawal if required Disposal of product containers	Sample and test Visual inspection	Quarantine, store until cleaned EPA-approved disposal	Production log and test sheets	Evaluate records
Purchased feed	Min	Employee training	Sample and test Storage, visual inspection	Reject load Quarantine, store	Receiving log, test sheets, and invoices	Check records Invoices
Receiving feedstuffs	CCP-1	Source verified Invoice date, description Employee training Only approved products	Sample every load, test or store Visual inspection product and truck	Reject load Quarantine, store until cleaned EPA-approved disposal	Receiving log, test sheet and invoices	Check records Invoices (receiving log-test log-in) by feeding mgmt and nutritionist evaluation
Feed facilities	Min	Regular examination	Visual inspection	Clean and inspect	Inspection record	Records mill and main office
Feed additives	CCP-2	Invoice date, description, and numbers Employee training Approved products	Additives inventory against inventory balance	Notify nutritionist Quarantine, withdrawal adjusted for group if need	Receiving log Invoices Use log	Check records and invoices (receiving log-use log, withdrawal report) before releasing

continued

FIG. 14-12 Hazard analysis critical control points outline for feed. *BQA,* Beef quality assurance; *CCP,* critical control points; *DOF,* days on feed; *WD,* withdrawal.

hamburger, the meat of which was derived from a single herd. The editorial that accompanied the report suggested that the study provided "the important missing link" between human disease and bacterial resistance resulting from the feeding of subtherapeutic levels of antibiotics to animals. However, the evidence is incomplete. First, the pathogenic bacterial strain was not recovered from the slaughterhouse or from the hamburger, all of which had already been consumed, and no cases of *S. newport* disease occurred in the cattle or in the people associated with the farm. Second, another processing plant in another state received half the carcasses from this herd and had no apparent problem. Third, the only *S. newport* organisms isolated from an animal that were of a strain identical with the outbreak strain came from a calf that died in an adjacent dairy herd. With regard to the use of antimicrobials in the feed of the feedlot animals, the report stated, "The beef cattle had been fed subtherapeutic amounts of chlortetracycline throughout 1982 for growth promotion and disease prevention, but no therapeutic concentrations of antimicrobials. The farmer added chlortetracycline to the feed by hand, approximately 100 g per ton of feed." However, this was not analyzed or proved, and there is no indication of how long the drug was used. Furthermore, the addition of

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BQA Hazard	CCP	Preventive Measures	Monitoring Procedures	Corrective Action	Records	Verification
Feed formulas	CCP-3	All formulas managed by nutritionist	Checked by nutritionist Estimated DOF against withdrawal Batch checked	Withdrawal errors Max level chart	Formulation sheets, batch sheets Feeders log	Check records (for-batch log) as used and before releasing
Batch/Load	Maj	Establish route and sequence Balance min Establish Min/Max and exception chart Employee Training	Batch check list Accumulation and total batch/load sheets, regular audits	Withdrawal errors Max level chart	Batch logs Truck log Feeders log	Balance logs
Feed delivery	Min	Employee training Establish route Loads match call	Balance load total against feeders log	Assign delivery balance load against delivery	Load records: group feed log	Check records (delivery-call) Rechecked before releasing
Cattle release	CCP-4	All withdrawal times met	Records of transferred cattle reviewed and balanced	Last-release	Release form signed	All forms examined before release

FIG. 14-12 cont'd For legend see p. 625.

an antimicrobial to the feed by hand at a rate of 100 g/ton would be imprecise at best.

According to Spika et al (1987), a 1985 outbreak of multiple-resistant *S. newport* in California "convincingly" demonstrated the entire chain of transmission. The outbreak strain was resistant to chloramphenicol, tetracycline, kanamycin, ampicillin, and sulfisoxazole and was characterized by a single large plasmid. Epidemiological studies identified ground beef as the suspect food vehicle, and many of the patients had consumed ground beef at fast-food restaurants. Microbiological and epidemiological studies traced the epidemic strain through the hamburger, back to meat-processing plants, and ultimately back to the farms from which the animals had been sent for slaughter. The isolates were from ill calves and cows from a number of dairy herds. Isolation of chloramphenicol-resistant salmonellae was associated with chloramphenicol use at those dairies. However, there is no information on how the drug was used, when it was used, how long it was used, and even whether it was used at all. Thus use was not proved. In the two outbreaks just cited, the human patients were receiving physician-prescribed oral antimicrobials for previously diagnosed illnesses. Oral antimicrobials can interfere with competitive bacterial antagonism, a natural defense mechanism for the control of bacteria.

An in-depth study conducted in 1989 by the Institute of Medicine of the National Academy of Sciences concluded that it was not possible to find a substantial body of direct evidence that conclusively established a human health hazard resulting from the use of subtherapeutic concentrations of penicillin and tetracyclines in animal feeds (Institute of Medicine, 1989).

More recently, the USDA and the Center for Veterinary Medicine of the Food and Drug Administration asked the National Research Council (NRC) to form a committee to examine and review the benefits and risks associated with drug use in the food-animal industry (National Research Council, 1999). The NRC assigned the task to the Board on Agriculture, and the Committee on Drug Use in Food Animals was convened. The committee was charged with reviewing, evaluating, and making recommendations related to the need for drugs and their availability and accountability in agriculture, the benefits and risks to human health and food safety associated with food-animal drugs, the development of food-animal drugs and the process of approval of their use, and the emerging trends in animal health care and the availability of alternative management practices for raising food animals. In particular, the sponsors stressed the importance of evaluating the class of drugs known as antimicrobials.

The committee concluded that the use of drugs in the food-animal production industry is not without some problems and concerns, but it did not appear to constitute an immediate public health concern; additional data might alter this conclusion. The greatest concern is associated with the use of antimicrobials in food animals in such a way that there is a potential for antibiotic resistance to develop in or be transferred to pathogens that can cause disease in humans. This report acknowledged that there is a link between the use of antimicrobials in food animals, the development of bacterial resistance to these drugs, and human disease—although the incidence of such disease is very low. The link between the animals fed antimicrobials and transfer of antibiotic resistant enteric pathogens to humans has not yet been demonstrated.

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The following table was reviewed with _____ **(owner/manager)**
To identify those areas appropriate to _____ **(beef operation)**
Min: Potential site of *minor* Problem (s = safety, p = production, q = quality)
Maj: Potential site of *major* Problem (s = safety, p = production, q = quality)
CCP: Problem will exist if not controlled at this point (s = safety, p = production, q = quality)

BQA Hazard	CCP	Preventive Measures	Monitoring Procedures	Corrective Action	Records	Verification
Cow/bull health	CCP-5	Health/nutrition appropriate to operation	Vet diagnosis of problem Palpation/ BCS/others	Adjust as Vet and examine Inject-SQ neck	Production records	Records checked by operator and vet
Calf health (birth)	Min	Cow in optimum condition at calving Environment appropriate to optimum calf Assist as needed Colostrum mgmt Employee training Approved products	Calving management	Adjust as Vet and examine Inject SQ neck	Calf health records	Check records to see all treatments and procedures recorded
Calf health early management	Maj	Individual ID Health appropriate to operation Withdrawal established Employee training Approved products	Vet diagnosis of problem Date, product ID, withdrawal	Set withdrawal, Inject SQ neck	Processing records	Check protocol against invoices of products and processing records
Pre-wean health	Maj	Individual ID Health appropriate to operation Withdrawal established Employee training Approved products	Vet diagnosis of problem Date, product ID, withdrawal	Set withdrawal Inject SQ neck	Receiving/ pen/yard sheet	Check protocol against invoices of products and processing records
Cattle receiving	CCP-6	Assume contaminated	Observe/record variation	Sort and examine	Receiving record	Records foreman Office
Processing products	Min	Group ID Name-serial numbers Withdrawal time Employee training Approved products	Set clear dates Inventory	Establish min sale date for group	Receiving/ pen/yard sheet	Check records (receiving-feed-hospital-main) before releasing
Pesticides management	Min	Employee training Pesticide use plan Approved products	Inventory	Lock and separate	Use records: (1) Individual (2) Premise	Check records before releasing

continued

FIG. 14-13 Hazard analysis critical control points outline for product use. *BCS,* Body condition score; *BQA,* beef quality assurance; *CCP,* critical control points; *SQ,* subcutaneous.

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BQA Hazard	CCP	Preventive Measures	Monitoring Procedures	Corrective Action	Records	Verification
Mass med	Maj	Group ID Withdrawal time Approved products	Projected sell date against withdrawal Inventory	LAST test non-performers	Receiving/ pen/yard sheet	Check records (receiving-feed-hospital) before releasing
Sickness	CCP-7	ID, date, product Protocol and established withdrawal Employee training approved products	Vet protocol, date, product, ID, withdrawal, est., sell date	Monitor and set withdrawal SQ neck, LAST non-performers	Health records	Check protocol against health records
Transfer, culling or feedlot release	Min CCP-8	Check withdrawal	Check withdrawal Records available	Withdrawal check Last test non-performers	Release form signed	Check records before releasing

FIG. 14-13 cont'd. For legend see p. 627.

A substantial change in the human health risk posed by antibiotic use would affect not only how animal drugs are reviewed, approved, and used, but also how food animals are produced. It should be noted that antimicrobials are still effective for their intended purposes at the recommended dosages.

Bacterial resistance to antimicrobials is the most important motivating factor in the development of new drugs to fight infections and in the modification of processes by which drugs are approved. Regulatory agency approval practices have improved in recent years and continue to do so. Reasonable balance in accountability, oversight, and veterinarians' access to alternative drugs has increased with the passage of Animal Drug Availability Act (ADAA) and Animal Medicinal Drug Use Clarification Act (AMDUCA). However, those are only temporary solutions to a continuing problem.

Unless new antimicrobials become available, even the extra-label use of antimicrobials is expected to become ineffective. There is a great need to understand better both the magnitude of the risk and the options available to minimize the risk while maintaining the benefits these drugs confer on agriculture. Constant vigilance in monitoring trends in antibiotic resistance in farm animals and humans is strongly encouraged.

New antibiotic drugs are needed to combat emerging animal diseases that do not respond to traditional drugs and so threaten public confidence in animal agriculture and human medicine. Professionals in human health care should be concerned that they do not have enough specialty antimicrobials to treat resistant and emerging infections in humans, as should veterinarians.

In the midst of the debate on the use of antimicrobials in beef cattle, it is obvious that feedlot consultants must emphasize prudent use of antimicrobials. This illustrates to those concerned about antimicrobial use in cattle that beef safety is an important consideration in modern feedlot medicine. Judicious use of antimicrobials will lessen the chances of bacteria becoming resistant, thereby prolonging their usefulness. In 1999 the AABP Board of Directors approved the AABP Prudent Drug Usage Guidelines (Box 14-11), which can serve as a framework for antimicrobial usage by feedlot consultants.

CULLING OF FEEDLOT CATTLE

Culling may be done at any point between examination of the cattle on arrival and a few weeks later, before they are placed on a high-energy diet. Diseases that justify culling include chronic unthriftiness and inappetence of undetermined etiology, chronic laminitis, chronic lameness caused by footrot, chronic bloat, chronic pneumonia, acute and chronic pulmonary abscess, and BVD. Each of these diseases leads to unthriftiness, and a clinical examination is necessary for diagnosis.

FEEDING PROCEDURES

In general, there are three phases in feeding feedlot cattle: starting, growing, and finishing. During the first few days after arrival and until the cattle are introduced to full feed, the traditional general recommendation has been to provide a good-quality roughage. The critical factor is to get the new animals to eat so that ruminal flora and function are restored. Nutritional management of newly arrived cattle focuses on getting them "on feed" as soon as possible. Receiving diets and feeding programs differ depending on the type of cattle, the available feeds, and the owner's objectives. Regardless of the program, however, there are some general principles that apply to the nutrition of newly arrived stressed cattle (Lofgreen, 1988). The intake of stressed cattle is low in the first several days after arrival, and it is necessary to feed them a nutrient-dense diet. A ration containing 50% to 75% concentrate along with grass hay for the first week has provided a good rate of gain. Preconditioned feeder calves and backgrounded cattle will usually start eating and drinking with a minimum of difficulty. Cattle should be fed twice daily or even more often during the adjustment period, so that those that do not eat can be identified and examined more closely. The use of self-feeders during the adjustment period makes it difficult to detect anorexic animals, because animals may eat at any time.

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BOX 14-11

American Association of Bovine Practitioner (AABP): Prudent Drug Usage Guidelines

The production of safe and wholesome animal products for human consumption is a primary goal of members of the AABP. In reaching that goal, the AABP is committed to the practice of preventive immune system management through the use of vaccines, parasiticides, stress reduction, and proper nutritional management. The AABP recognizes that proper and timely management practices can reduce the incidence of disease and therefore reduce the need for antimicrobials; however, antimicrobials remain a necessary tool to manage infectious disease in beef and dairy herds. In order to reduce animal pain and suffering, to protect the economic livelihood of beef and dairy producers, to ensure the continued production of foods of animal origin, and to minimize the shedding of zoonotic bacteria into the environment and potentially the food chain, prudent use of antimicrobials is encouraged. Following are general guidelines for the prudent therapeutic use of antimicrobials in beef and dairy cattle.

1. The veterinarian's primary responsibility to the client is to help design management, immunization, housing, and nutritional programs that will reduce the incidence of disease and the need for antimicrobials.
2. Antimicrobials should be used only within the confines of a valid veterinarian-client-patient relationship; this includes both dispensing and issuance of prescriptions.
3. Veterinarians should properly select and use antimicrobial drugs.
   a. Veterinarians should participate in continuing education programs that include therapeutics and emerging and/or development of antimicrobial resistance.
   b. The veterinarian should have strong clinical evidence of the identity of the pathogen causing the disease, based on clinical signs, history, necropsy examination, laboratory data, and past experience.
   c. The antimicrobial selected should be appropriate for the target organism and should be administered at a dosage and route that are likely to achieve effective levels in the target organ.
   d. Product choices and regimens should be based on available laboratory and package insert information, additional data in the literature, and consideration of the pharmacokinetics and pharmacodynamics of the drug.
   e. Antimicrobials should be used with specific clinical outcome(s) in mind, such as fever reduction, return of mastitic milk to normal, or to reduce shedding, contagion, and recurrence of disease.
   f. Herd pathogen susceptibility and therapeutic response should be monitored periodically, especially for routine therapy such as dry cow intramammary antibiotics, to detect changes in microbial susceptibility and to evaluate antimicrobial selections.
   g. Products should be used that have the narrowest spectrum of activity and known efficacy *in vivo* against the pathogen causing the disease problem.
   h. Antimicrobials should be used at a dosage appropriate for the condition treated and for as short a period of time as reasonable (i.e., therapy should be discontinued when it is apparent that the immune system can manage the disease, reduce pathogen shedding, and minimize recurrence of clinical disease or development of the carrier state).
   i. Antimicrobials of lesser importance in human medicine should be used in preference to newer generation drugs that may be in the same class as drugs currently used in humans, if this can be achieved while protecting the health and safety of the animals.
   j. Antimicrobials labeled for use for treating the condition diagnosed should be used whenever possible. The label, dose, route, frequency, and duration should be followed whenever possible.
   k. Antimicrobials should be used extra-label only within the provisions contained within Animal Medicinal Drug Use Clarification Act (AMDUCA) regulations.
   l. Compounding of antimicrobial formulations should be avoided.
   m. When appropriate, local therapy is preferred over systemic therapy.
   n. Treatment of chronic cases or those with a poor chance of recovery should be avoided. Chronic cases should be removed or isolated from the remainder of the herd.
   o. Combination antimicrobial therapy should be discouraged unless there is information to show an increase in efficacy or suppression of resistance development for the target organism.
   p. Prophylactic or metaphylactic use of antimicrobials should be based on a group, source, or production unit evaluation rather than considered standard practice.
   q. Drug integrity should be protected through proper handling, storage, and observation of the expiration date.
4. Veterinarians should endeavor to ensure proper on-farm drug use.
   a. Prescription or dispensed drug quantities should be appropriate to the production-unit size and expected need so that stockpiling of antimicrobials on the farm is avoided.
   b. The veterinarian should train farm personnel who use antimicrobials on indications, dosages, withdrawal times, route of administration, injection site precautions, storage, handling, record keeping, and accurate diagnosis of common diseases. The veterinarians should ensure that labels are accurate to instruct farm personnel on the correct use of antimicrobials.
   c. Veterinarians are encouraged to provide written guidelines to clients whenever possible to describe conditions and instructions for antimicrobial use on the farm or unit.

From American Association of Bovine Practitioners Prudent Drug Use Guidelines, *Bov Pract* 34(1):73, 2000.

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When cattle have become adjusted to the starting ration and there is no evidence of acute respiratory disease or major infections, the animals may be started on the high-energy growing and finishing rations. A widely accepted and successful practice is to use a complex mixed ration consisting of grain, chopped roughage, protein supplement (if necessary), and the necessary vitamins and minerals. The level of grain is increased and the level of roughage decreased every few days until the predetermined levels are reached for the growing or finishing rations. With this method, feeder calves can be adjusted to a growing ration and yearlings to a finishing ration in 15 to 20 days, usually without carbohydrate engorgement or bloat. In large feedlots with many pens of cattle at different phases of the feeding program, outbreaks of carbohydrate engorgement occur when cattle are accidentally fed a finishing ration when they have only become adjusted to lower-energy rations. A high level of accuracy is necessary in the feed mill and by the personnel delivering the feed to the respective pens. Complete and thorough mixing of the feed must be ensured at all times.

ANIMAL WELFARE IN THE FEEDLOT

Since the 1980s a significant percentage of society has expressed concern about the morality of raising farm animals under intensive conditions (Janzen, 1990h). They believe that livestock production is contrary to the best use of the world's resources for humans' well-being. It is believed that the grains fed to feedlot cattle could be better used to feed humans in developing countries. Feeding animals in confinement in what is perceived to be overcrowded conditions is considered inhumane. The transportation of beef calves to an auction mart where they are sorted, mixed into saleable groups, sold by public auction, perhaps deprived of feed and water for 24 to 36 hours, and then transported to a feedlot and mixed with other cattle, where they ultimately become ill with acute respiratory disease, is considered by some animal welfare and animal rights activists to be unnecessary and cruel.

The feedlot production practices that produce this concern include marketing, stressors, mortality rate, branding, dehorning and castration performed without local anesthesia, delays in treatment of sick animals, inadequate handling facilities, cruel handling of animals, inadequate ground surface conditions that make the feedlot uncomfortable for the animals, and failure to cull and destroy animals affected with incurable illnesses.

The feedlot industry must pay attention to the concerns of organized animal welfare groups. Good feedlot design is important to ensure animal comfort. Handling facilities must be modern and efficient and must not induce animal attendants to be cruel to animals when they are being moved from one location to another; excessive force should not be used to get the animals to move. The pen checkers and treatment crew must be educated about the signs of pain and discomfort associated with certain illnesses and how cattle can be handled humanely.

The veterinarian should emphasize good feedlot design and equipment that will ensure comfort for the animals and minimize pain and stress associated with handling procedures. The veterinarian must also be a vigilant guardian, denouncing inhumane practices and encouraging sound animal welfare management.

BENEFITS OF A HEALTH MANAGEMENT PROGRAM FOR THE FEEDLOT

Feedlot operators who engage veterinarians for programmed preventive medicine invest money for this service because the veterinarian saves them money in the process. In Texas studies the economic losses caused by respiratory diseases alone in feedlot cattle have been estimated at $80/treated animal. This includes loss from shrink, poor feed use, inefficiency of gain, death, lowered carcass quality, and treatment of sick animals. In a study of disease in 407,000 yearling feedlot cattle in Colorado, the morbidity rate was 5.1%, the case fatality rate was 18.9%, and the population mortality rate was 1%. Respiratory tract diseases were the most common and accounted for 75% of illnesses and 64% of the deaths. From these limited data, it would appear that herd health programs can provide significant economic benefits to feedlot cattle operations.

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CHAPTER 15

Health and Production Management in Swine Herds

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What does the pig farmer require from the veterinarian? . . . . The fundamental needs of the modern day unit are to maximize production and efficiency, analyze the results and hence the return on investment. . . . The achievement of maximum profitability, however, must be carried out within the economic constraints and accepted practices of animal welfare.

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The primary reason for domestication of swine was to provide a source of animal protein as food for humans. The unique flavor of pork as human food also contributed to the domestication of swine. During the first half of the twentieth century, pork was the primary meat source in many parts of the world because of its high fat content. In human populations that have high energy requirements, pork fat is an excellent source of highly palatable energy. If the unique culinary qualities of pork were a major reason for domestication, selection programs emphasizing pork quality that lead to improved palatability may have a major impact on consumer demand for pork.

The body of knowledge and the clinical skills of veterinary medicine devoted to the health management and production of swine have expanded tremendously in the last two decades. The swine industry has maintained the consumer demand for pork in comparison with beef and has consistently reduced its cost of production. Much of the success in pig production has been in concert with effective disease control and improvement in productivity. Leadership by the veterinary profession in record keeping and analysis of health and production data and providing of consultation advice on facilities and operational design have helped control diseases and improve productivity. This chapter outlines and describes the methods available to the veterinarian to continue leadership in this consistently changing industry.

The swine industry can be considered an intermediate between the beef and poultry industries. The industry is currently going through a level of consolidation and vertical integration, which occurred in the poultry industry, particularly in the production of broilers many years ago. Historically, the swine industry was similar to the beef industry, with small holdings and an extensive method of rearing, particularly for sows. Recently there has been the development of large centralized facilities for the growing and finishing of pigs, often from many small extensive swine herds. Historically, pigs were fed a variety of diets consisting of grains and by-products from other agricultural enterprises such as skim milk and garden wastes. Pork and pork by-products such as lard were highly regarded within communities as being easily processed for storage.

The swine industry has undergone an extensive transformation since World War II. Consolidation, specialization, intensification, and mechanization have been the central features in the evolution of agriculture. The predominant theme has been improved labor efficiency, and the means to this end involved the substitution of machines for horses and manual labor. Agriculture evolved swiftly from a way of life to a business, and, as competition for the labor force intensified, producers moved to increasingly larger equipment to replace the traditional sources of farm help. Only increasing the scale and intensity of individual operations could offset the resulting escalation of the capital investment required. Increasing farm size was accompanied by consolidation of the hog industry—*a marked decline in the number of production units and an increase in the number of pigs marketed per producer and in total annual marketing*. Specialization in the swine industry in North America began in about 1950, continued into the 1990s, and is still occurring at the beginning of the new millenium. The changes are aptly described in "Positioning Your Pork Operation for the 21st Century" (Boehlje, 1995). Small farms have left the American industry, so that where there were 670,000 farms in 1980, there were only 183,000 in 1996.

The changes in the swine industry are similar to other industrial evolutions. After the decentralized mixed enterprises, farms that specialized in pork production emerged. They still tended to involve extensive operations but tended to use products that were grown on farm, primarily corn and soybeans within the Midwestern United States. If there were modifications into more intensive pig production, they usually involved providing intensive farrowing facilities that allowed greater control of the environments for newly born piglets. In many cases there was still delineation between weaned pig production and growing and finishing units. Many farms considered pig production as an ancillary enterprise to the primary goal of corn production. Sow management was often considered labor-intensive and thus many corn farmers chose to buy pigs at approximately 20 kg and rear them for market at approximately 110-kg live weight.

Changes in methods of a production were relatively few until late in the twentieth century. In many cases pig production was not the primary source of income, and entry into and exit out of pig farming were common. This going "in" and "out" of the industry was invariably in response to market pork prices, and, in turn, price was in response to the supply of pigs. This response to price created the "hog price cycle," which occurred every 4 to 5 years when the supply of pigs would rise and then fall.

However, productivity was relatively poor in these enterprises when compared with current levels. Efficiency in feed

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conversion and reproductive performance were low, and there were relatively few alternatives for improvement within the structure of production in place. The alternative was to create a more intensive method of production that allowed improvements in productivity measures and thus profitability. Intensification of swine production involved much risky experimentation by swine producers. Penning, flooring, ventilation systems, nutrition schemes, and scale were the subject of many experiments and much improvement, especially during the '60s and '70s. Concurrent with this changing technology came a renewed emphasis on lean pigs. This experimentation resulted in both increased productivity and new challenges, both in understanding the mechanisms of these levels of productivity but especially in disease control (Herrick, 1997).

Historically, veterinarians providing service to swine herds concentrated on the control of infectious diseases and reproductive performance. Although it was called *herd health,* much of the effort went into identification of pathogens and the development of control strategies that reduced the effect of these diseases on production. Intensification of pig production created many new expressions of old diseases and the appearance of some new ones. Pathogens such as *Actinobacillus pleuropneumoniae* devastated many initial attempts at high-density, large-scale pig production. Initial attempts at its control were unsuccessful, since much of the reliance was based on interventions using vaccines and therapeutic antibiotics. Alternative strategies such as elimination of the pathogen from the herd, *"all-in, all-out"* (AIAO) production, and alternative ventilation systems were subsequently and more successfully used. Similar experiences with the porcine reproductive and respiratory syndrome have reinforced the need for veterinary medicine to shift the emphasis from curative medicine of individual animals to health and production of the herd.

Practitioners of veterinary medicine soon realized that the control of pathogens was not an end to itself (Kavanagh, 1998). Pig production led the way in developing record-keeping systems that reflected the objectives of the farm and induced a producer to analyze and improve productivity on the farm. Veterinarians historically assumed that minimization of pathogens would maximize productivity. In many cases, this was not true and therefore veterinarians began to emphasize productivity, with disease control being a secondary concern. The aims of maximizing pigs per sow per year and feed conversion became common goals on these farms.

With this emphasis, remarkable improvements were seen in maximizing reproductive performance of the herd. Record-keeping systems illustrated large herd differences in indexes such as farrowing rates, preweaning mortality rates, and litter size. Changes were made in genotypes to achieve increased reproductive output, and other changes such as diet and lactation lengths were examined. To achieve these improvements in productivity the veterinarian began to take much more of a *whole-farm* approach and became knowledgeable about not only production indexes but also genetics, housing, reproduction, nutrition, and personnel management.

The emphasis on productivity, however, did not adequately consider the need for control of the costs of inputs. It became evident, especially with improvements in grower and finishing pig productivity, that there was a need for greater emphasis on cost control. The whole-farm approach was expanded to include knowledge of the factors involved in minimizing the cost per pound of gain, often guided by partial budgeting. This led to advances in nutrition and feeding in which alternative diets were fed in the nursery, and the nutrients were more closely aligned with the requirements of the pig. Moreover, feed delivery and feeder management was refined to minimize feed wastage.

The industry continues to develop from cost minimization to profit maximization. Recently, much more emphasis has been placed on increasing the value of the output, namely market hogs, to improve profitability. Factors such as weight, leanness, and carcass yield have gained greater emphasis. In addition, there has been a greater sensitivity to the requirements of the consumer and the packer and the demands on pig production have been expanded to include the control of antibiotics residues; pale, soft, and exudative pork; and other contaminants such as *Salmonella typhimurium.*

There has been considerable change in the past, and the future holds more of the same. The imbalance between supply and demand has led to considerable financial hardship for independent pork producers during the late 1990s. Furthermore, there is an increased amount of integration or cooperation between packers and pork producers so that price discovery is becoming difficult. In addition, there is considerable benefit in coordinating pig production and the meat processing industry so that there is an increased amount of common ownership of both pork production and meat processing. This in turn has induced even more change in swine production and has allowed for considerable increases in the scale of units. Currently, reproductive units as large as 25,000 sows are being established in the American Midwest. Discomfort with these changes in pig production along with an increased public sensitivity over production methods and the resultant level of odor, manure and changes in purchasing practice in the community has led to regulatory constraints on further expansion (Penny, 1998).

Future economic survival in the swine industry will depend on some essential factors: (1) keeping useful records for the monitoring and evaluation of performance so that improvements in every aspect of production can be made quickly and efficiently, (2) developing an understanding of the cost-price equation, which means that producers who want to make a profit have to be better than the average, as defined through bench-marking, (3) using strategic contracts with buyers and suppliers to manage risk, and (4) evaluating capital management and economic feasibility to maintain support through price fluctuations.

The skills and abilities of the industry to consider many challenges and constraints are a probable long-range major constraint to pork production. Effective analysis and consistent implementation of solutions to challenges are crucial. Cost minimization and maximization of productivity are often been presented as methods of partially meeting a goal of profit maximization. However, decisions now must also include consideration of ensuring a place in the market. Productivity improvements must be seen as inevitable and as part of the goal of swine production.

It must be recognized that stability of the process has been underemphasized. Increasingly, there is emphasis on robust technology instead of simply productive technology. Methods are being examined and tested, which are predictably producing pigs that are sometimes not to their maximum potential, but to the potential at which it can be done on a regular basis. There is emphasis on reducing the variability of the growth rates within a herd and reducing the variability of output of the sow herd on a weekly basis, all in an effort to make the overall enterprise operate more smoothly. To meet these demands in the swine industry, some objectives in pig production can be considered.

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OBJECTIVES IN PIG PRODUCTION

Efficient Use of Variable Cost Inputs

In most cases, the major variable input is feed. Fig. 15-1 illustrates an example of the component costs of a hog production system. Feed efficiency and feed costs are major concerns that must be monitored. The minimization of costs has been a historic emphasis in successful swine production. An economic analysis of swine operations in Hawaii showed that the efficient use of inputs such as feed, most of which is imported and therefore has high costs, is more important to profitability than is maximizing pigs weaned per sow per year (Sharma et al, 1997).

Efficient Use of Fixed Costs (Capacity Utilization)

In most cases the fixed inputs are labor and facilities, and thus it is important to ensure that capacity is used efficiently. Thus the planning of introducing pigs and looking closely at optimum turnovers is an important part of growing pig management. Nonetheless, it cannot be the primary purpose, because it must be done within the realm of the other constraints of the barn. In many cases, maximization of output, especially pounds per square foot, is an ineffective measure because it does not maximize profits.

Improve the Quality and Value of the Pigs

Improvement of the quality and value of the pigs may appear intuitive but historically has been examined rarely within pig record-keeping systems. Too much time can be spent in cost minimization when, in fact, other areas that can improve profitability should be examined. This is an area that examines opportunity to improve profits instead of real costs and thus is often not as intuitive as cost minimization.

Create, and Improve on, a Robust System to Achieve the Above Goals

Not only must the system for achieving the aforementioned goals be efficient, it must not "crash and burn" but improve. Pig production and marketing is relatively complex, unstable, and influenced by current economic constraints. Therefore production and marketing plans change and will continue to change depending on the performance of the pigs among other factors. Thus any record-keeping system must be current and is a "backbone" of swine health management.

Staying Ahead of the Competition

To begin an analysis of health and production in a swine enterprise, some level of comparison is needed. Benchmarking is a process that has been called inherently useful and useless. Many have argued that the best measure of success in pig production is the historic productivity of the particular farm compared with other farms. However, productivity itself may not be a fair measure. There has been much frustration with benchmarks, since they have often been used by outside agencies such as banks to measure the success of farms. These benchmarks have been used with little regard for their accuracy, comparability, and utility.

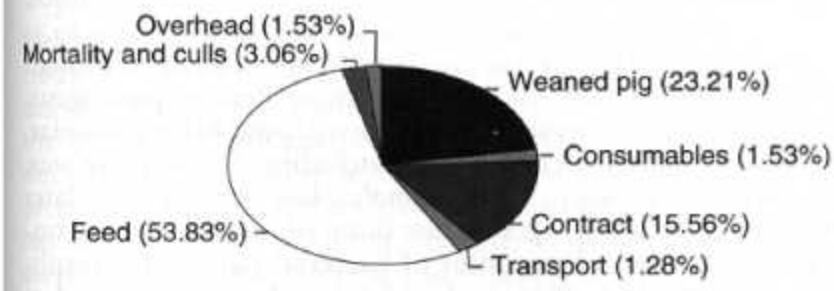

FIG. 15-1 Breakdown of costs of production.

CHANGES AND TRENDS IN SWINE INDUSTRY AND HEALTH MANAGEMENT

The U.S. National Animal Health Monitoring System (NAHMS) 1995 National Swine Study provides statistically valid national estimates of parameters related to swine management on operations throughout the major pork-producing regions of the United States, and it examines changes and trends in the swine industry from previous national swine surveys (Losinger et al, 1998a,b; USDA: APHIS:VS, 1995). Phase I collected information about management and production in swine operations. Phase II focused on the phase of the pork industry by collecting information from operations with more than 300 finishing pigs.

Data on changes in the U.S. Pork Industry from 1990 to 1995 are available in a publication of October 1997 from http://www.aphis.usda.gov/vs/ceah/cahm/Swine/sw95trnd.htm. Some of the main findings follow:

Demographic Changes in the U.S. Pork Industry

- The swine population continues to increase.
- The number of U.S. swine operations decreased more than 30% from 1990 to 1995.
- The proportion of herds with an inventory of 1000 or more head continued to increase.
- A larger proportion of the U.S. pig inventory is shifting to herds consisting of 2000 or more head.

Health and Productivity

- A steady increase in the number of pigs saved per litter has occurred each year since 1990.
- From 1990 to 1995, reported stillbirths and mummified fetuses per litter decreased nearly 25% (from 0.87 to 0.65), whereas born alive per litter decreased 1%.
- The total number of pigs born per litter decreased (10.34 to 10.02), but the percent born alive per litter increased from 91.59 to 93.51.
- Preweaning deaths per litter decreased 20% (from 1.10 to 0.88). Preweaning deaths per litter were 11.62 were in 1990 and 9.39 in 1995.
- Number of pigs weaned per litter was 8.37 in 1990 and 8.49 in 1995.
- The causes of preweaning deaths reported in the two surveys were as follows:

	1990 (%)	1995 (%)
Diarrhea	23.9	15.1
Laid on	40.4	48.7
Starvation	20.4	20.5
Other problems	9.0	6.6
Unknown problems	6.3	9.1

  Piglets being laid on is the leading cause of preweaning deaths. A significant decrease in diarrhea-related deaths was reported.
- The culling rate of breeding-age females culled over a 12-month period as a percent of sow and gilt inventory for 1990 and 1995 was 43.5% and 41.2%, respectively.

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- The percent of pig deaths in the nursery ranged from 2.4 to 2.3 from 1990 to 1995, respectively.
- The major causes of death in the nursery are diarrhea and respiratory disease, which account for about 50% of deaths. Other known and unknown problems account for about 41%.
- Deaths in the growing and finishing phases of production ranged from 1.8% to 2.1%.
- The major cause of death in the growing-finishing pigs was respiratory disease.

Management Changes in the U.S. Pork Industry

- Pen-mating using multiple females and one or more boars continued to be the most frequent breeding technique.
- The percentage of operations using artificial insemination (AI) doubled from 1990 to 1995 (from 3.8% to 7.8%, respectively). The percentage of sows and gilts bred by AI increased from 1.1% to 11.1%.
- The use of antibiotics in sows, gilts, and boars increased significantly.
- Approximately half of operations practiced AIAO management in the farrowing phase. The overall inventory of females managed as AIAO increased from 55% to 65%. Larger operations are using AIAO management in the farrowing phase.
- In 1990 the most frequent waste management system used was hand cleaning (41% of operations), which declined to 28% in 1995. In 1995 pit holding was used most frequently (41%).
- The percentage of operations using dewormers, injectable antibiotics, and mange-lice treatment as preventive practices for piglets increased over the 5 years; use of injectable or oral iron decreased.
- The average weaning age of piglets decreased approximately 3 days (from 28.5 to 25.7 days) on an individual pig basis but remained unchanged for the average operation.
- The proportion of nursery pigs managed as AIAO increased 16% during the 5-year period (from 53.5% to 69.8%), but the percentage of operations practicing AIAO management remained unchanged at about 47%.
- Pigs left the nursery at an average age of 60 days.
- The percentage of growing-finishing pigs managed as AIAO increased from 24% to 51%, and larger operations adopted AIAO management in the growing-finishing phase more frequently than smaller operations.
- The average market age on growing-finishing operations decreased from 183.2 days to 176.8 days.
- Overall, in 1995 (compared with 1990), the average pig was weaned 3 days younger, stayed in the nursery 1.7 days longer, and had about the same length of stay in the growing-finishing phase (118 days).
- The majority of swine operations continued to be independent producers who marketed their own animals. Total inventory marketed through contract producers increased over the 5-year period but still accounted for less than 10% of pig inventory.
- A pocket diary or calendar was the most widely used record-keeping system, and use increased from 64% to 72% over the 5-year period. Record card and service bureau-based systems were used less frequently, while computer-based systems gained popularity (increasing from 8% to 13.5% over the 5-year period).
- The percentage of operations using vaccines regularly for the following diseases were erysipelas (49%), *E. coli* (38%), parvovirus (44%), leptospirosis (47%), and porcine reproductive and respiratory syndrome (22%).
- Separation-quarantine and health testing of new arrivals decreased for breeding animals (33.6% to 19.5% for females; 61% to 33% for males) and increased for feeder pigs (2% to 10%). Of those producers who separated-quarantined new breeding stock, approximately two thirds also health tested them.
- Less than one half of all operations (49%) used veterinarians for any purpose in 1995. Large declines in the use of veterinarians occurred for vaccination consultation, individual pig treatments, and provision of drugs.
- Most carcasses (pigs that died) were disposed of by burial on the farm (59%). Burning and renderers decreased significantly; 10% of operations used on-site composting of carcasses.
- Use of cats as the primary means of rodent control decreased from 88% to 71% in all operations over the 5-year period. Other methods included traps (13%) and bait or poison (74%).
- For biosecurity, 40% of operations allowed only employees to enter the premises. Showers or footbaths were rarely required on those operations that allowed others on the premises (feed-delivery personnel and livestock handlers).
- The distances to nearest swine operation remained relatively stable in distribution, with over 70% being within 3 miles apart. Most operations were 5 or more miles away from a swine market.
- Rates for condemnations for deads increased from 1990 to 1995 (from 0.782 to 1.467/1000 pigs slaughtered, respectively) and remained the largest single reason for condemnation. Condemnation rates for abscess, pyemia, and arthritis declined. The number of carcasses condemned for residues decreased.
- The most frequently isolated *Salmonella* serotypes isolated from swine are *Salmonella choleraesuis, derby,* and *typhimurium*.
- The number of outbreaks of foodborne illness associated with pork or ham has declined over the last 20 years.

Advances in Health Control

No one single factor has the ability to influence performance, health, and well-being of pigs as severely as exposure to infectious diseases. Exposure to bacterial and viral pathogens occurs frequently in the life of an individual animal and can spread throughout large populations at a rapid rate. Depending on the level of immunity within the population and the degree of management under which they are raised, the clinical effect can be severe, particularly if concurrent infection of multiple pathogens occurs. Therefore the need to mitigate the effect of disease factors to improve animal health and productivity has led to the evolution of disease-control strategies for pig production systems.

A major breakthrough in understanding the relationship of disease control and pig production occurred in the early 1980s with the adaptation of segregated production based on the principles of medicated early weaning (Alexander et al, 1980). Further work in this area emphasized the advantage of age-segregated rearing of weaned pigs (Connor, 1990). As this work progressed, weaning age decreased to as low as 7 to 10 days throughout the global industry. Although this practice caused the elimination of certain pathogens, such as *A. pleuropneumoniae* and *Mycoplasma hyopneumoniae*, it enhanced the effect of others, including *Streptococcus suis, Haemophilus parasuis,* and *Actinobacillus suis*. It was later found that weaning ages of less than 14 days caused inconsistent mucosal colonization of bacterial pathogens, resulting in the mixing of infected and non-infected naive piglets at weaning (Pijoan, 1997) As maternal antibodies declined, these pathogens were shed from colonized to noncolonized

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pigs, leading to elevated postweaning mortality rates (4% to 12%). This work, in combination with a reduction in breeding herd prolificacy and longevity associated with early weaning, resulted in the global industry selecting longer lengths of lactation. Whereas the length of lactation may have been fixed by welfare laws (≥21 days in Europe), other countries have chosen to select intermediate lactation lengths (e.g., 16 to 18 days) in order to maximize health status and to minimize the negative impact on breeding herd productivity.

In the late 1980s, reports of a devastating epidemic of reproductive failure, in conjunction with a high level of respiratory disease, were relayed throughout the pig-producing areas of the world. The problem continued for 3 years, until Wensvoort and colleagues (1991) isolated a viral agent, fulfilled Koch's Postulates, and defined the disease of porcine reproductive and respiratory syndrome (PRRS). Called the "disease of the decade," no other health problem has caused such extensive losses and frustration to so many producers around the world. A brief review of this infectious disease is presented in the section on reproductive failure of swine.

Efforts to control PRRS initially focused on the postweaning period through the adaptation of nursery depopulation (ND), a protocol to prevent the horizontal transmission of the virus through the removal of the entire nursery pig population on a given day (Dee and Joo, 1994a,b; Dee et al, 1997a,b). Yet, as breeding herd inventories increased (≥1000 sows), so did the inability of ND to control the disease long term because of recurrent transmission of the virus within the breeding herd and the generation of infected piglets before weaning. The concept of breeding herd subpopulations demonstrated that infected and noninfected adult animals could coexist within the same population (Dee et al, 1995b). Through the use of a battery of serological tests, virus shedding was demonstrated from chronically infected sows to naive animals, indicating that varying levels of exposure to the virus within populations did indeed exist.

A prominent risk factor that contributed to the development of subpopulations was the replacement gilt. Recurrent episodes of PRRS induced reproductive failure after direct introduction of seronegative or actively infected gilts into the breeding herd (Dee and Joo, 1994a,b; Dee et al, 1995a). This led to the development of several strategies for the introduction of gilts into commercial farms. The primary emphasis of these strategies consisted of the introduction of younger animals, in larger groups, more frequently throughout the year. Today, it is not uncommon for gilts to enter a designated development facility at weaning or at 25-kg body weight. Furthermore, the concept of establishing farms where the sole purpose is to raise, breed, gestate, and farrow gilts has been proposed as a management strategy to emphasize gilt performance and health status. These types of operations, called "parity 1 (P1) production farms," would provide P1 females for commercial farms, thereby eliminating the need for a gilt pool in these operations.

During the early 1990s the concept of commingling weaned pigs from a number of sow sources evolved. Initially, it seemed to be an excellent strategy to maximize production and health status. However, the inability to control the spread of PRRS virus (PRRSV) through early weaning reduced its effectiveness in commercial pig production. The problem arises from the inability to equalize the health status of infected sow herds, leading to subpopulations of weaned pigs, some infected and others noninfected.

In order to counteract this variability in health status, the ability to completely fill and empty a facility on a given day with a single source of pigs AIAO by airspace") led to improved postweaning performance, in contrast with animals housed under an AIAO by-room (continuous-airspace) basis (McManus, 1991). This concept was further expanded, with the end result being the development of the weaning-to-finishing building (Connor, 1990). This facility houses pigs from the time of weaning until they are marketed, eliminating the stress of mixing at 25 kg and reducing labor cost while taking advantage of the benefit of stage depopulation. Data from wean-to-finish facilities collected from over 28,000 pigs indicate mortality rates of 3.1%, feed conversion ratios of 2.54, and daily growth rates of 0.69 kg from entry (4.2 kg) to market weights of 115 kg.

Molecular Diagnostics

The recent advances in molecular diagnostics, such as polymerase chain reaction (PCR) and its application to the swine industry, has led to an improved level of accuracy in determining the presence of certain pathogens within pig populations (Braun et al, 1999). PCR has the potential to improve speed, sensitivity, and specificity of diagnostic testing. PCR assay is not recommended as a herd screening diagnostic test because of its expense. Its use should be reserved for situations in which it is essential to know whether a specific pathogen is present in tissues or body fluids.

PCR assays are available for both porcine viral and bacterial agents. Viruses that cause the following infections can be detected: PRRSV, transmissible gastroenteritis (TGE), porcine respiratory coronavirus (PRCV), and pseudorabies (PR).

Bacteria that can be detected are: *Lawsonia intracellularis, Brachyspira* (formerly *Serpulina) hyodysenteriae, Salmonella* spp., and *Mycoplasma* spp. PCR is a sensitive diagnostic tool for confirmation of the presence of *L. intracellularis* from mucosal samples (Jordan et al, 1999).

A reverse transcriptase PCR for amplification of the open reading frame 6 region of the PRRS viral genome has enhanced the level of "quality health assurance" in breeding swine. This test, in conjunction with serologic assays (ELISA), are effective means to accurately profile the pattern and chronology of viral infection within pig populations. Furthermore, PCR assists in detecting peracute infection before generation of antibodies. Possessing a high level of sensitivity and specificity, PCR has enhanced detection of persistently infected animals within breeding herds.

Biosecurity in Swine Production

Biosecurity is any practice or system that prevents the spread of infectious agents from infected animals to susceptible animals or that prevents the introduction of infected animals into a herd, region, or country in which the infection has not yet occurred. Biosecurity, an integral part of any successful livestock enterprise, reduces the risks and consequences of introducing an infectious disease. The components of biosecurity, which include management and placement programs, farm layout, decontamination, pest control, and immunization, directly affect productivity and profitability. Biosecurity for the swine herd is defined as the protection of a swine herd from the introduction of infectious agents (Amass and Clark, 1999).

The information required to consider biosecurity protocols for the swine herd includes the origin and method of transmission of pathogens and the survival characteristics of the pathogens (in dust and uncleaned rooms, flooring, soil, manure, water supplies, and composted carcasses). Cleaning and disinfection of housing facilities and equipment are of paramount importance in infectious disease control.

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Infectious diseases in the swine herd can be spread among pigs within the herd or introduced into the herd by infected pigs; contaminated semen; aerosol transmission; rodents, flies, mosquitoes, and ticks; birds; domestic and nonporcine feral animals; feed, including the feeding of garbage; vehicles; personnel; and visitors (Amass and Clark, 1999). Foot-and-mouth disease (FMD) virus and swine influenza virus are the only swine pathogens that have been shown to be transmissible from infected pigs to humans. Whether or not people (workers, veterinarians, and others) should shower before entry into a production unit is controversial. There are no reports of the effect of showering on the carriage of bacteria and viruses.

For some diseases it is desirable to prevent the spread of infectious agents from a certain age group of animals to younger age groups. One example is the attempt to control the spread of the virus causing porcine reproductive and respiratory syndrome in pigs by depopulation of the nursery pens.

The introduction of new infections into herds can be prevented or minimized by purchasing animals directly from herds that are known to be free of a particular disease. The adoption of this principle requires awareness of the possibility of purchasing unknown infected animals and testing animals for the infection before entry into the herd. It may also require keeping the introduced animal in quarantine for several weeks after arrival before it is mixed with the other animals. Producers can evaluate the effectiveness of biosecurity protocols by recording information about the movement of people, animals, feed, and equipment to, from, and within their production facilities. Records can also help identify the likely source of disease introduction should an outbreak of disease occur.

Biosecurity practices for the prevention of infectious disease introduction are critical in today's global industry. A comprehensive review of the biosecurity principles for swine units is available (Moore, 1992). A summary of the peer-reviewed literature on biosecurity in the swine industry is also available (Amass and Clark, 1999). Many decisions concerning biosecurity protocols in swine herds are currently based on empirical experience of producers and veterinarians, and not on scientific research. Consequently, research is needed in many areas to validate current protocols or to develop new scientifically based biosecurity protocols for the pork industry.

As an example, in 1985, the transmission of *M. hyopneumoniae* through aerosols and its survivability outside the pig was researched. This helped establish minimum distances for the placement of units (3.2 km apart) and the recommended period of downtime for personnel before entering swine operations (48 hours). Biosecurity can be further enhanced through the use of AI. However, studies have demonstrated the capability of transmitting PRRSV by raw and extended semen (Yaeger et al, 1993; Swenson et al, 1995).

Advances in Nutrition and Feeding

The steady advances in the science of animal nutrition that occurred during the first half of the twentieth century were quickly adopted by the swine industry. Although the period before the 1960s was highlighted by identification and establishment of most of the nutrients required by pigs, in the past 40 years only one item—selenium—has been added to the list of required nutrients commonly added to swine diets. Much progress has been made in refining the requirements of nutrients that were already considered essential. The prediction of nutrient requirements based on growth requirements has been refined, and a number of computer models have been developed.

The feeding and nutrition of young pigs has changed markedly. When begun, the practice of weaning pigs at 3 weeks of age was invariably associated with problems such as postweaning diarrhea. Today, pigs averaging about 5.5 kg are housed in modern nursery facilities, where they attain a weight of 22 kg by 9 weeks of age with a mortality of no more than 3%. Weaned pigs are now raised in nurseries with carefully controlled environments and specialized diets.

Many aspects of feeding technology received considerable research attention, such as the design of equipment for automatic feed delivery, the consequences of diet dilution or other methods of controlling feed intake, and processing techniques to enhance nutrient digestibility and nutrient density. Linear programming for formulating least-cost diets led to the development of modern computer programs that can formulate diets according to the cost and nutrient composition of available dietary ingredients.

Performance Trends

In the same period under consideration, dressing yield increased from 69.5% to 71%, and percentage yield of backfat decreased from 14.6% to 5.3%. In Canada, there has been a steady increase in the proportion of carcasses that index above average (index of 100) in a measure of the anticipated yield of trimmed retail product. The reduction of backfat also has continued at an undiminished rate. Although there is no evidence in either the United States or Canada to indicate the relative contributions of genetics, nutrition, and management to these changes in carcass merit, the steady rate of change is highly suggestive of a substantial and continuous genetic component. The development of larger herds as well as a greater economic incentive to succeed may also have contributed to a gradual improvement in the average levels of most production components, including carcass merit.

There has been considerable improvement in sow productivity in the last 20 years. The average number of pigs marketed per litter in the United States has increased from eight to almost nine in just the last 7 years (Fig. 15-2).

It is necessary for veterinarians, hog producers, and others associated with the swine industry to use the same terms when considering pig production. Stage One (breeding production stage) is where the breeding females and boars are kept and managed for the purpose of reproduction. Stage Two (nursery production stage) is the stage associated with nursery pigs, and Stage Three (finishing production stage) deals with finishing pigs. The term *Isowean* includes segregated weaning, early weaning and age-segregated rearing. The different types of production systems are also described (one-site, traditional two-site, two-site Isowean, and three-site).

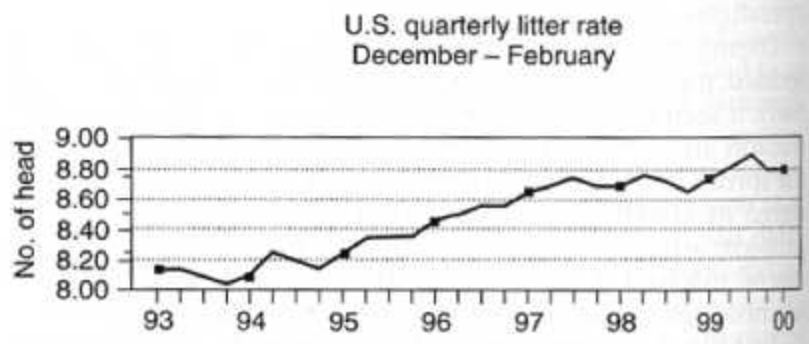

FIG. 15-2 Pigs marketed per sow farrowed, as estimated by U.S. Agricultural Statistics Service, March 2000.

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INDUSTRIALIZATION OF SWINE INDUSTRY

Food-producing animal production is moving toward an industry structure of fewer, larger production units that feature centralized control of technology and production processes. This is known as the intensification or industrialization of food-producing animal agriculture. Over the last few decades, companies involved in the production of meat and poultry have vertically integrated their operations through contracts with producers who grow the animals. These agricultural organizations own feed mills to produce feed, produce their own pigs on farrow-to-finish and finishing farms, and raise their own replacement stock by multiplying high-genetic purchased reproductive animals. They may own an abattoir and even a meat-processing plant. Owner-operated farms are often referred to as independent farms, in comparison with those belonging to integrated organizations, referred to as integrated farms. Integration is a way for a company to ensure a reliable supply of animals for processing into consumer-ready products.

A survey in Quebec, Canada, of owner-operated, swine-breeding farms and integrated organizations found that production tended to be more specialized and concentrated in integrated operations (Ravel et al, 1996). More new practices have been adopted on integrated farms, and their stockpersons have a more proactive style of management in farrowing quarters. Swine production methods, especially piglet rearing, are different between independent farms and integrated organizations specializing in swine production. These differences are related to organization size. The specialization, concentration, and intensification of production, as well as the pursuit of higher performance through the adoption of new practices, are considered essential by integrated organizations, given the importance of their investment.

The industrialization of U.S. animal production is taking place in nearly every state. Typically, animals are grown within 50 miles of a processing facility because of the expense of shipping live animals. Proximity to feed mills is also desirable because of the costs of shipping the large quantities of feed required to grow pigs to slaughter weights.

A major consideration in locating production facilities is the disposal of animal wastes: land must be available relatively near the growing facilities for that purpose. The producer is responsible for removal and disposal of dead animals, as well as recycling the animal wastes that accumulate during the growing process. Also important is an adequate supply of workers for production and processing.

Vertical integration of animal production is designed to increase efficiency, lower expenses, and produce additional value. In vertical integration, one firm owns and controls the raw material, the means of production, and the final product. Producers enter into contracts with integrators to provide housing for the animals, feed them, ensure their health, and provide for waste disposal. The producer typically owns the housing and the feed storage facilities that are used in the production of the animals. The integrators own the animals. Contracts stipulate what feeds and animal health products farmers use, as well as the prices paid for their products.

The industrialization of agriculture has a number of positive and negative aspects. It is important to understand the real and perceived effects of integrated production systems. These include a variety of both positive and negative influences on social and economic conditions and on the environment. Most producers and governmental agencies believe the swine industry has had major benefits for the rural economy. Industry leaders or government officials may not recognize the negative impacts associated with industrialization.

Industrialized, corporate farming fosters the rapid adoption of technology. Some changes in technology can also negatively influence small-scale producers. The diffusion of agricultural technology can widen the gap between large and small farmers. One consequence for the early adopter of certain technologies is either windfall profit or loss. Once the use of the technology is widespread, the total productivity of an industry increases, which leads to oversupply and a reduction in the price of the product. Technology can widen the inequality gap, since early innovators are the ones who can afford to adopt and profit from new technology.

The effects of large-scale swine operations on rural health have been examined (Thu and Durrenberger, 1998). Rural health is the physical, social, economic, environmental, and political well-being of people living in rural areas. Considerable research is being devoted to understanding various pieces of the complex puzzle (e.g., odor, manure application, ground and surface water protection), whereas less time and energy are spent articulating the range of issues involved and their interrelationship.

The swine industry has undergone a dramatic shift in the past decade, characterized by increased concentration of production, loss of independent swine producers, geographical shift of production within and outside the United States, and the growth of large-scale swine operations. The number of U.S. swine producers has declined precipitously from 750,000 in 1974 to 157,000 by the end of 1996. Between 1994 and 1996 one out of every four producers left the business. By the end of 1996, 3% of producers, representing the largest corporate operations in the United States, produced 51% of all the pigs, while 21% of all pigs were grown under contract. In Iowa, 55% of all new swine facilities permitted by the Iowa Department of Natural Resources from 1987 through 1995 were owned by or under the effective control of large-scale corporate swine producers.

Large-scale operations are defined as firms that possess the following combination of features: (1) management, labor, and ownership are separate, (2) family labor plays a limited role in the operation, (3) owners, management, and labor do not live on or near the operation, and (4) a non-family corporate or company organizational structure.

The characteristic features just described of emerging large-scale swine operations reflect the continuing industrialization of agriculture. It is a food production system heavily dependent on fossil fuel–based energy inputs such as fertilizers, machinery, pesticides, and gasoline. Anthropologists claim that, based on measures of energy expended per calorie of food produced, industrial agriculture is the most inefficient form of food production in the history and prehistory of humankind. Large-scale operations characteristically substitute capital-intensive, fossil fuel-based technology for people. Concentration of production and distribution into relatively few firms, which integrate highly specialized operations such as food processing and marketing, is common. Also, a highly specialized political apparatus extending into national, regional, and local governing bodies, as well as state-supported institutions to support and replicate the system, is typical of human organizations associated with industrial agriculture (Thu and Durrenberger, 1998).

Proponents and opponents of industrial agriculture have respectable support in academia. Frequently invoked evidence for the economic advantages of industrial agriculture are the wide availability of abundant food at extremely low cost to consumers and the record productivity and efficiency of modern farmers. In contrast, critics of industrial forms of agriculture point to the narrow focus of economic measures of development and efficiency that typically exclude assessments of the social, environmental, physical, psychological, political, and rural economic health of people. Most

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of these issues are not incorporated into economic analyses of food production (treated as externalities), but each has a distinct, often measurable, and human cost, as summarized briefly here.

The range of rural consequences of large-scale swine production to be assessed fall into six categories: (1) air quality, (2) water quality, (3) human health, (4) community social health, (5) rural economic health, and (6) political health.

Air Quality

Air quality issues can be divided into two general areas: odor and public health. Most of the attention to air quality issues has concentrated on odor, such as identifying sources of odor, measuring it, and developing control techniques. Less attention has been paid to the potential consequences of odor on the health of neighbors, even though some studies indicate deleterious human health consequences are present.

The evidence collected thus far indicates efforts to control odors are not synonymous with addressing the potential public health problem. Moreover, no systematic data are being collected to determine which forms of production, particularly which kinds of producers, are more likely to be responsible to their neighbors in controlling air quality.

Water Quality

In 1996 an EPA Comparative Environmental Risk Assessment was completed for Iowa that demonstrated water quality related to the changing swine sector was a primary environmental and social concern statewide (Thu and Durrenberger, 1998).

The evidence justifies rural resident concerns. The Iowa Statewide Rural Well Water Survey shows that in north-central Iowa, 10% to 15% of all wells (all depths) exceed the recommended drinking water limit for nitrate-nitrogen and over 30% of all water supplies are positive for total coliform bacteria. Runoff related to livestock manure is the number one source of fish kills in Iowa streams (Thu and Durrenberger, 1998). Despite the concerns and evidence, little systematic data exist to assess the actual performance of large-scale swine operations relative to contamination to surface water, groundwater, and precipitation. No systematic data are being collected to determine which forms of production, particularly which kinds of producers, are more likely to be responsible for good water quality. In the National Swine Study between 1989 and 1991, the nitrates in drinking water, at the concentrations found, were not associated with farrowing swine health or productivity parameters examined (Thu and Durrenberger, 1998).

Human Health

One of the most well researched areas related to swine production is the relationship between exposure to the interior environment of swine confinement production and worker health. Twenty-five studies from the United States, Canada, Sweden, Denmark, the Netherlands, Germany, and England have consistently found a number of work-related health problems among swine confinement workers. Approximately 25 percent of all swine confinement workers have one or more respiratory conditions. However, there remains the unanswered long-term health question concerning the health risks for workers spending 40 or more hours/week, which is typical of large-scale operations.

People working inside confined swine production environments are exposed to certain health hazards associated with organic dusts, gases, and odors (Donham, 1998). People working in these confinement operations include owner-operators, employees, children, veterinarians, and other service workers. Workers may spend several hours per day in these facilities preparing feed, feeding animals, cleaning buildings, sorting and moving animals, giving vaccines and other treatments, and working at various other management and maintenance procedures.

Bioaerosols, fine airborne dust containing bacteria and bacterial products, are a major problem. These complex mixtures originate primarily from the animals and dried feces and feed. Bioaerosol particles contain approximately 25% protein. One third of breathed particles are so small that they are not filtered out in the nose and throat and thus enter the airways; the smallest particles may reach the lungs. Bioaerosol and gas concentrations increase during the winter months when facilities are tightly closed and ventilation rates are reduced to conserve heat. Typical ventilation systems in swine buildings are designed to control heat and humidity but do not necessarily reduce bioaerosol or gas levels adequately to ensure a healthy environment for humans or animals.

Workers may develop flu-like symptoms with coughing and sneezing, wheezing, chest tightness and phlegm, and sometimes a fever with muscle aches. Swine confinement workers in the United States, Sweden, and Canada have similar rates of acute bronchitis—approximately 55%, or about twice the rate of chronic bronchitis (Donham, 1998). Veterinary students visiting swine confinement units experienced eye irritation, headache, and tiredness (Jolie et al, 1998). Cough, nasal and throat irritation, and sinus inflammation were the most prevalent respiratory tract symptoms that usually developed the day of the visit and disappeared within 3 days after exposure. The presence of clinical signs was not significantly different between students who wore a mask during the farm visit or those who did not. Students with preexisting allergies were more likely to develop respiratory symptoms than students who did not have allergies (Jolie et al, 1998). Two-strap respiratory protective face masks reduce the total and respirable dust concentrations more so than the one-strap face masks, but they are still not highly effective. Surveys of swine producers regarding employee health and safety have found a need for training materials on first aid, animal handling and care techniques, air-quality monitoring, and lung function testing for employees (Tripp et al, 1998). Employee health and safety protection is part of doing business, and there is a need for educational and research programs to address the issues.

Hydrogen sulfide gas is most hazardous when the manure pits are located directly beneath the production buildings. The gas poses a potentially lethal hazard when the liquid manure is agitated, which operators commonly do to suspend the solids so the pits can be pumped out. During agitation, the gas can be released rapidly, increasing from levels of less than 5 ppm to lethal levels of over 500 ppm within seconds. Numerous cases have been reported of workers and animals dying or becoming seriously ill when hydrogen sulfide levels increases from agitated pits.

The decomposition of animal urine and feces produces gases, most notably ammonia and hydrogen sulfide, which affects the health of workers.

Community Social Health

Social issues refer to personal, family, neighborhood, and community relationships and quality of life. Measurable social problems result from absentee-owned large-scale agriculture. Community divisions are created and frequently become acutely disruptive as the result of large-scale swine operations. More fundamental than any single issue is the

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deep-seated frustration that people feel from the lack of adequate local means of problem resolution. The lack of local control causes an escalating social pathology in many rural areas. A continual recurrence of discords and attempts to find an outlet has led to a pattern of community distrust that is at odds with core values of rural Iowans. This intense conflict acts as a pressure cooker, and with no outlet attitudes and behaviors that resonate with extremism can and will develop.

Rural Economic Health

The rural economic impact from smaller and more diversified farms is better than from large-scale swine facilities, because they add greater value to the community economy (Thu and Durrenberger, 1998). Considerable research indicates that a better measure of industry health for rural areas is not the total volume of hogs produced, but the number of farmers producing those hogs.

Hogs are not as important as people. Traditional economic assessments of large-scale swine facilities have been overly narrow in scope in dealing with job creation and tax bases, and generally ignore environmental, social, and human health costs. Large-scale swine facilities are by their very nature intended to displace people with capital intensive technology, and it is therefore erroneous to project job creation gains because the displacement of independent swine producers will result in a net job loss.

Political Health

Perhaps the most disturbing aspect of swine industry change is its consequences for the democratic health of the country. Anthropological cross-cultural research clearly demonstrates that concentration of power over the production and distribution of a precious research is antithetical to democratic process. This is illustrated quite clearly in the following quote from former U.S. Senator Robert Morgan's experience from North Carolina (Thu and Durrenberger, 1998):

Before I became State Attorney General of North Carolina, I spent some years as a country lawyer. We lawyers all knew each other and we took our cases down to the courthouse where we went up against each other but all played by the same rules. When big business steps in it is no longer that way. This situation was brought to my attention in early 1992 when a group of homeowners and small farmers asked me to represent them in their efforts to protect themselves against damage done by a large-scale hog operation. The defendants brought in a law firm with more than fifty lawyers and assigned several to our case. These lawyers had virtually unlimited time and money. The industry's resources helped the defendants in more subtle ways. When attorneys for the plaintiff, armed with a court order, inspected the facilities, they found that the owners were accompanied by several professors from North Carolina State University, a land grant college with responsibilities for agricultural research.

Framing the Priorities and Envisioning the Future

The relative importance of the six issue areas just outlined can be gauged by asking a simple question: "If it's broken, why can't I get it fixed?" If we accept the evidence that there are in fact significant water quality, air quality, economic, social, and worker health problems associated with large-scale swine operations, we are then faced with the question of why we have failed in our efforts thus far to fix them. The answer is that the political system, the system that should respond to these problems, has also been broken along the way. This is the fundamental problem. By unjustly and incorrectly dismissing the voices of rural Iowans and rural Americans as overly emotional, unscientific, antigrowth, or anti-agriculture, our political leaders have violated a fundamental democratic tenet of trust and faith in due process by exchanging human dignity for the hollow rhetoric of economic development. More fundamentally, trust lost is not easily regained. Loss of faith in our leaders, in our political system, in our academic institutions, and in our country is a heavy price to pay.

The future holds hope and promise. In our vision for the future we must remember that people are always more important than commodities; the best measure of industry health is the number of people producing hogs, not the number of hogs produced. Assumptions that define and promote ideas of productivity and efficiency as inevitable and of industrialized swine production as natural convince those who suffer the costs that there is nothing they can do about it. Something *can* be done about it. Recent strides in sustainable agriculture have succeeded in establishing a foothold relative to the dominant industrial agricultural paradigm. Sustainable agriculture is often perceived to be associated with specific farm practices to deal with such issues as soil erosion or decreasing fertilizer use. Criticism is often leveled at sustainable agriculture that it is nebulous and ill defined, and that it has no pragmatic program or mechanism for ensuring profitability among farmers who make the transition. However, we must remember that any newly emerging system of adaptation requires a range of variation to increase its likelihood of success. Sustainable agriculture would be doomed to failure if its tenets were clearly defined and rigidly practiced at the outset. The underlying point of sustainable agriculture is not precisely what it is, but what it means and why it is emerging.

Agricultural industrialization can have adverse effects on rural communities. There may be loss of political power because of small farmers' not being as organized as specialized commodity groups, outmigration of rural populations, and displacement of farm workers because of mechanization. Furthermore, the simultaneous demise of small farms and the rise of large-scale agribusiness in a community often brings rising unemployment and declining economic well-being for the community. For example, industrialized operations tend to contract with national suppliers and distributors rather than local suppliers.

Large livestock farms clearly benefit the farm economy. The industry is economically viable and probably will remain so because the worldwide demand for products is expected to continue to grow in the future. However, there are winners and losers as a result of industrialized agriculture. Because of the demise of the independent producers, service jobs have been lost. Many small feed mills and other farm service firms are no longer in business. These and other impacts need to be balanced against the economic effects.

SUSTAINABILITY OF THE SWINE INDUSTRY

Sustainable swine production systems are defined as those that combine production and management techniques to enhance profit and improve the ecological and socioeconomical surroundings. Over the long term, the systems should maintain or enhance the environment and resource base, the quality of life for the producers and society as a whole, the profit level of producers, and the quality of pork produced. Swine production is rapidly changing to fewer and larger production units. At the interface of sustainable

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agriculture and swine production are several levels of issues: the farm, the rural community, the society or consuming public, and the ecosystem or environment. The challenge beyond identifying issues is to incorporate sustainable concepts into profitable, ecologically based swine production systems.

For long-term success the social, economic, and environmental dimensions of industrialized swine production need to be carefully considered at the farm, rural community, consumer, and ecosystem levels (Honeyman, 1996). Rapid changes in the swine industry structure influence all of these levels in fundamental ways. Young, beginning producers are vital to the future of swine production and must have access to technology, genetics, markets, and information. Manure nutrient management is the key linkage between swine and crop production. Quality pork to meet the consumer's needs helps ensure a vibrant industry. New sustainable alternatives are needed that select the appropriate technologies and combine them into management-intensive systems coupled with crop production. Virtually every issue involving sustainable swine production provides opportunities for research, education, dialogue, and change. The implications of sustainable swine production are a wholesome balanced environment; healthy rural families and communities; many profitable, modest-sized, family-based swine-crop farms; and quality pork.

Pork Quality

Pork quality is a significant problem for the U.S. swine industry. The U.S. pork supply has about 16% pale, soft, and exudative (PSE) pork, and 10% is dark, firm, and dry (DFD). Increasingly, hogs are being purchased on a carcass merit basis. Therefore leanness and muscling are becoming more important to producers. The porcine stress syndrome (PSS) gene is related to both leanness and PSE-DFD pork. The selection of pigs for fast deposition of lean may lead to lower levels of intramuscular fat or marbling, which may produce drier or less tasteful pork. Consumers are also concerned about the use of antibiotics in swine production and the potential for violative levels of drug residues in pork. Pork Quality Assurance (PQA) programs and producer education activities have been successful in reducing drug residues.

Swine Manure Management

Waste management has become a hotly contested topic with the expansion of intensive livestock operations, especially large-scale swine operations. The large number of animals confined on these operations results in large amounts of animal waste with a relatively high potential for pollution. As controversy has arisen over livestock waste, local and national governments have responded with stricter environmental regulations. Other consequences of industrialization of agriculture are the effects on the environment adjacent to human populations. Two frequent concerns expressed whenever large-scale swine enterprises are discussed are water pollution and odors. Odor is often the most immediate impact, but citizens are also concerned about water quality and other issues (Miner, 1999).

Pig manure is primarily a mixture of urine and feces, and it contains undigested dietary components, endogenous end products, and indigenous bacteria from the lower gastrointestinal tract. Manure contains a variety of organic compounds (complex to simple in nature), inorganic compounds, and, potentially, feed additives, depending on the makeup of the diet. Odoriferous volatile organic compounds, short-chain volatile fatty acids, and other volatile carbon-, nitrogen-, and sulfur-containing compounds from microbial fermentation in the gut of pigs can be emitted immediately after feces are excreted. Furthermore, the release of urinary ammonia from the enzymatic conversion of urea can occur within a short time after excretion. Depending on the type of manure-handling system used and duration of storage, odors can be emitted during organic matter decomposition of manure. Methods used to control odor emissions from manure have included dilution with water; low temperatures; solid-liquid separation; aeration; anaerobic digestion; application of enzymes, chemicals, bacterial cultures, and masking agents; filtration of ventilation air; and diet manipulation. Control of on-farm odors with feed or manure additives is often cited as an odor control option for producers. The manipulation of diets to reduce odors is feasible and practical (Sutton et al, 1999).

Swine producers are under increasing pressure from regulators, legislators, neighbors, and environmental groups about manure management. Manure has been cited as a contributor to the increasing nitrate levels of groundwater. Improper manure management is a contributor to the increased phosphorus, nitrate, and fecal coliform bacteria in some rivers. To maintain a viable swine industry, manure management issues must be addressed and action taken in a proactive manner.

Manure handling systems vary among producers. Systems include manure collection, storage, and use (Schmitt et al, 1996; Schmidt et al, 1996). One major difference in manure handling is the use of solid or liquid systems. Collection systems are used to collect and remove manure from a confinement facility. Manure storage structures include deep pits, earthen structures, and above- and below-ground concrete tanks. Manure application to cropland is the traditional method of manure use. Cropland application methods affect odor and gas emissions, water quality, and nutrient availability to crops. Solid manure can be broadcasted on the soil surface, whereas liquid manure can be either broadcasted on the soil surface or injected under the soil surface. Surface-applied manure, either liquid or solid, can be incorporated into the soil through several tillage methods. The location of manure application in relationship to surface water is a critical issue in preventing contamination of surface and ground waters.

Most large-scale swine operations constructed to date have incorporated anaerobic lagoons into overall manure treatment and storage strategies. Well-designed lagoons provide three specific functions:

1. They provide a location for anaerobic bacteria to decompose the residual organic compounds into more easily handled end products. This means a conversion of the solid material into liquids, which is similar to the process that occurs in a household septic tank system.
2. They provide a storage volume to accumulate treated and partially treated manure until the time for convenient or economically productive application of the material to cropland.
3. They provide a facility to capture and store any contaminated runoff that might be generated by rainfall on manure-contaminated surfaces that may be outside the roofed areas.

Two major concerns are water pollution and odor. Water pollution can occur whenever large quantities of organic waste materials are concentrated in one area. A lagoon may overflow, or, if lagoon contents are purposefully drained into a surface waterway, the material may contaminate the receiving water. Groundwater pollution may occur from leakage from the lagoon or manure storage reservoir moving down-

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ward into groundwater. Also, the application of excessive effluent to cropland may cause more nitrogen being applied than is used by the crop. The nitrogen may be transported beyond the root zone and may eventually appear in groundwater as an increased nitrate concentration. Odors are primarily the products of anaerobic decomposition of manure. Heavily loaded lagoons are a notorious source of odor.

There are alternatives to minimize the environmental impact of large swine production units (Miner, 1999). Technology and management techniques exist to achieve higher levels of environmental acceptability. Engineers and construction professionals have the ability to construct basins that do not leak or that have dikes that will not erode and dump large quantities of manure into receiving streams. Groundwater sampling and monitoring techniques are available to identify when lagoons are leaking. Manure management options to reduce odor are available. Enclosed anaerobic digesters can reduce organic content by 90% while producing a biogas that can be converted to electricity. Lagoons can be covered and the collected gas diverted to a soil absorption system. Permeable covers for lagoons are also available that greatly decrease odors.

Composting Dead Animals

Improper disposal of dead pigs can lead to odor problems, transmission of pathogens, and water contamination. Three typical methods of dead pig disposal are rendering, incineration, and burial. Composting is now being practiced on several thousand farms in the United States, primarily on poultry farms for the handling of mortalities (Kashmanian and Rynk, 1995). Composting is an alternative method for the disposal of fetal placenta and dead pigs (Morrow et al, 1995). A compost pile requires nutrients, water, and oxygen. The process disintegrates most of the carcasses, including most of the bones, and reaches temperatures sufficient to kill all of the *Erysipelothrix rhusiopathiae*, pseudorabies virus, and most of the *Salmonella*. There is little odor associated with the pile and few flies. Veterinarians have the opportunity to include the management of dead pig disposal in the consulting services they offer.

Pork Quality Assurance Program

The National Pork Producers Council (NPPC) in the United States introduced the PQA program in 1989 as a three-level management education program. The PQA program emphasizes good management practices in the handling and use of animal health products and encourages producers to review their approach to health management of their herds. It is a multi-level producer education program to enhance the quality of pork sold to the world's consumers.

The PQA program is for all pork producers, regardless of the size of their operation. The benefits of participation for the individual producer are to the following:

- To improve management practices
- To avoid violative drug residues
- To decrease production costs
- To increase awareness of food safety concerns

Pork Quality Assurance: the Veterinarian's Role

The PQA program consists of three levels. Level I is a self-study program for producers that covers the importance of food safety to the pork industry, producer attitudes and responsibilities, use of animal health products, the current regulatory system, and on-farm testing. Level II is a producer self-review of the information provided in Level I. Levels I and II are contained in the same booklet as Level III. The booklet is available from NPPC. Levels I and II are also available at NPPC's website at http://www.nppc.org.

The producer completes the Level III program in association with a verifier. Verifiers can be veterinarians, university agriculture extension personnel, and agricultural educators. The Level III program contains ten good production practices (GPP). The GPPs ensure compliance with the Food and Drug Administration (FDA) compliance policy guide "Proper Drug Use and Residue Avoidance by Non-Veterinarians (CPG 7125.37)" and meet the minimum expectations of the government and packers. The first six GPPs address food safety; the other four focus on the efficient production of a quality product. After completion of the educational and evaluation program, both producer and verifier sign the verification form. The signed form is then sent to NPPC. A certificate of program completion is then sent to the producer. The producers then review their herd health program with their verifiers annually and recertify every 2 years.

Benefits of participating as a verifier for veterinarians include the following:

- Shows producers that veterinarians are current with the industry.
- Strengthens the image of the veterinarian's practice as a source of educational materials.
- Reinforces the importance of the veterinarian-client-patient relationship (VCPR) in responsible use of animal health products.
- Expands client base through increased interactions with current clients and the addition of new clients through referrals.
- Provides a basis for discussing the role of veterinarians in herd management practices.
- Contributes to the pork industry's long-term goal of making pork "the meat of choice" in the twenty-first century.

A set of slides with a script is available from the NPPC that can be used by veterinarians or others to efficiently present the PQA program to groups of producers.

Food Safety in the Pork Industry

The issue of food safety has been influenced and maintained by highly publicized outbreaks of foodborne disease in humans. These outbreaks have stimulated consideration and revision of regulations for food inspection in packing plants and have produced consumer groups' advocation of the control of foodborne pathogens in animal production systems. The United States has recently become a net exporter of pork, and quality assurance of product is becoming a focus of competition in export markets (Davies, 1997). Perceptions of food safety can have profound effects on consumer attitudes, government regulations, and market access. Quality assurance standards can have a profound effect on domestic and international markets for pork-producing countries.

The major foodborne pathogens in the United States and relative importance of pork as a source are as follows (Davies, 1997):

Pathogen	U.S. Department of Agriculture Ranking	Relative Importance of Pork
Salmonella	1	++
Campylobacter	2	+
Toxoplasma gondii	3	+++
E. coli 0157:H7	4	—
Listeria monocytogenes	5	+
Trichinella spiralis	6	++++
Yersinia enterocolitica	6	++++

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Human trichinellosis, a parasitic nematode infection with worldwide distribution, is caused by tissue-dwelling roundworms of the species *Trichinella spiralis*. The parasite is acquired by eating raw or inadequately cooked meat products containing encysted larvae. Historically, pork products from domestic swine have been the principal sources of infection in the United States; however, meat from a variety of game animals has also been responsible for infections in humans. The incidence of human trichinellosis continues to decrease since national reporting was initiated in 1947. However, the continued identification of cases related to commercial pork consumption and the histories of consumption of uncooked meat indicate the continuing need for public education about trichinellosis and the dangers of consuming inadequately cooked meat (Moorhead et al, 1999).

A trichinella herd certification pilot project was successfully completed in northeast Iowa, and an eradication program may be in the near future. Control steps include the following:

1. Eliminate exposure to domestic and wild animals including domestic and feral cats
2. Implement and maintain an effective rodent control program
3. Eliminate sources of infection from feed
4. Avoid environmental exposure to toxoplasma oocysts
5. Prevent or control cannibalism among pigs

Out of a total of 80 million swine slaughtered annually in the United States, the number of carcasses identified with cysticercus lesions *(Cysticercus cellulosae)* is extremely low, ranging from 1 through 44 during each of the 10 years (Saini et al, 1997). Swine cysticercosis (unlike cattle cysticercosis), with man being an alternative intermediate host, poses serious public health concerns with sometimes fatal consequences manifested through neurocysticercosis *(Cysticercus cellulosae)* (Saini et al, 1997). Although human cysticercosis is still rare in the United States, recent reports have indicated an increase in diagnosed cases. These are primarily the result of an increasing number of immigrants and international travel to and from endemic areas.

Hazard Analysis of Critical Control Points

The U.S. Department of Agriculture (USDA) Food Safety and Inspection Service has required hazard analysis of critical control points (HACCP) principles be put in place in meatpacking plants. The HACCP system is designed to prevent food safety problems instead of relying on finding them after they happen. The pork producer's responsibility under the packer's HACCP plans is to supply the packer with animals that are free from violative tissue levels of antimicrobials and chemicals and free from physical hazards such as broken needles and other metals in the meat.

The seven basic principles of the HACCP system include the following:

1. Identify hazards.
2. Find critical control points in the process.
3. Establish critical limits for each critical control point.
4. Monitor critical points.
5. Take corrective action if monitoring shows there are deviations outside the limits of a critical control point.
6. Keep records on each critical control point.
7. Verify that the HACCP plan is working correctly.

Application of the HACCP system in packing plants is done by identifying groups of hazards that can affect the safety of the meat, such as the following:

- Microbial contamination
- Chemical hazards such as antimicrobial and chemical tissue residues
- Physical hazards, such as the accidental presence of broken needles or other metals

The slaughter of swine is an open process with many opportunities for the contamination of the pork carcass with potentially pathogenic bacteria (Borch et al, 1996). The major contamination points during slaughter are pig-related, such as fecal and pharyngeal, and environmental. HACCP and good manufacturing practice (GMP) in swine slaughter must be focused on limiting this spread. The pathogens that may contaminate pork include *Campylobacter* spp., *Salmonella* spp., and *Yersinia enterocolitica*, all of which originate from the pig. Contamination of the carcasses with these pathogens may be limited, provided that only strict slaughtering procedures are used. Other organisms such as *Aeromonas* spp., *Listeria monocytogenes/Listeria* spp., and *Staphylococcus aureus* may be endemic in the processing environment, and since they can be controlled by proper cleaning and disinfection, they are useful as indicators for the success of GMP.

The packers address microbial contamination through an in-plant HACCP process. Producers must, however, help control antimicrobial and chemical residues and physical hazards. The producer is responsible for properly observing withdrawal times to ensure there are no violative antimicrobial tissue residues.

The Food and Drug Administration (FDA) has published a compliance policy guide, "Proper drug use and residue avoidance by non-veterinarians," that outlines the producer's responsibilities when using animal health products. Following these guidelines ensures the products continue to be available for use when necessary. They should be observed whether the product is administered as an injection, spray, or through the feed and water.

For responsible use of animal health products the producer must do the following:

1. Identify and track animals to which drugs were administered. They can be identified by the following:
   - Individual
   - Pen
   - Lot
2. Maintain medication and treatment records that identifies the following:
   - Animals treated
   - Date(s) of treatment
   - Drug(s) administered
   - Who administered the drug(s)
   - Amount administered
   - Withdrawal time before slaughter
3. Properly store, label, and account for all drug products and medicated feeds.
4. Obtain and use only veterinary prescription drugs through a licensed veterinarian based on a valid VCPR.
5. Educate all employees and family members involved in treating, hauling, and selling the animals on the following:
   - Proper administration techniques
   - Observance of withdrawal times
   - Methods to avoid marketing adulterated products for human food

Several bacterial species pose a food safety hazard, with salmonella being the most prevalent. One of the challenges regarding on-farm control of salmonella is potential high prevalence of infection but only mild or even no clinical signs in the pigs. In fact, many serovars that cause illness in humans are not pathogenic in swine. The following control methods are recommended to decrease salmonella on the farm and in so doing, decrease salmonella prevalence in pigs delivered to the slaughterhouse:

1. Periodic thorough pressure washing and disinfection of facilities

2. AIAO pig flow
3. People movement within and between farms; all accompanying potential fomites should be managed to reduce carrying salmonella
4. Control of the rodent population
5. Prevention of birds entering the facilities
6. Clean-up of feed spills outside the facility to discourage birds, rodents, and other wildlife from accumulating at the site
7. Vaccination with *S. choleraesuis* has been reported to reduce shedding of *S. typhimurium* (Gibson et al, 1999) and *S. derby* (Groninga et al, 2000)
8. Feed ingredients are free from salmonella contamination
9. Proper ventilation of facilities to decrease survival of the bacteria in the environment

Veterinarians are a critical component of the food safety control program. They have a unique understanding of the production conditions that exist on the farm and how these might be managed to decrease exposure to important zoonotic pathogens.

WELFARE OF SWINE

A concern of society is the welfare of pigs raised under intensive conditions. When pigs were kept extensively in an outdoor system with a large living space, their welfare was normally considered to be adequate. However, current husbandry methods usually lead to pigs remaining indoors during their entire life, and the numbers kept per unit is steadily increasing. Ruth Harrison's book, Animal Machines (1964), subsequently led to the Brambell Report (Brambell, 1965), which recognized the possible detrimental effect of limited space, diet, ventilation, bedding, and companionship on animals' well-being. The report observed, "It is because of these various restraints imposed on animals by the artificial environment of intensive husbandry that the role of welfare has become so crucial today. Welfare is a wide term that embraces both the physical and mental well being of the animal. Any attempts to evaluate welfare, therefore, must take into account the scientific evidence available concerning the feelings of animals, that can be derived from their structure and function, and also from their behavior." The establishment of the Farm Animal Welfare Council in 1979 in Great Britain followed this report. The Council has been given the responsibility of reviewing the welfare of farm animals on agricultural land, at markets, in transit, and at the place of slaughter. It advises agriculture ministers of any legislative or other changes that may be necessary. In 1988 the Farm Animal Welfare Council made an assessment of pig production systems and recommended the banning of high temperature-high humidity (e.g., sweat box) system for finishing pigs, the phasing out of multi-tier weaner pig pens, and that the dry sow should not be housed with stalls and tether systems (both girth and neck types) and that, as a matter of urgency, the government should introduce legislation to prevent all further installation of units of these designs (Farm Animal Welfare Council, 1988).

Various types of stressors occur mainly as a result of intensification of production processes at many points in the life of a pig (Ayo et al, 1998). Common stressors in modern pig production include high ambient temperature or heat stress, effects of road transportation, changes at weaning, overcrowding, aggressiveness and cannibalism, nutritional inadequacies, and veterinary procedures (e.g., vaccination, castration, tail amputation, collection of blood samples). As a result of stress, pigs may lose weight or gain very slowly, convert feed to meat less efficiently, sustain physical injury, become more susceptible to diseases, or have reduced meat quality.

The behavior of the animal attendants in swine herds affects the behavior of pigs; the behavior of the pigs, in turn, is an important factor in the effectiveness of managing modern systems (Seabrook, 1988). The attendant can have a profound positive or negative effect on productivity of the animals. The role of the pig stockperson is not just important from an economic viewpoint; it is vital for animal welfare too. In the United Kingdom, the *Code of Recommendations for the Welfare of Livestock-Pigs* states: "Stockmanship is a key factor because, no matter how otherwise acceptable a system may be in principle, without competent, diligent stockmanship, the welfare of animals cannot be adequately catered for" (Seabrook, 1988).

Agriculture Canada (1993), in coordination with the Canadian Federation of Humane Societies, has published "Recommended code of practice for care and handling of farm animals: pigs." The voluntary code is intended to be used by the industry, scientists, and animal welfare groups as an educational tool in the promotion of sound husbandry and welfare practices. The recommendations attempt to define high standards of pig production and well-being in commercial, research, educational, and other farm operations. This code of practice is currently being revised and updated and can be viewed at http://carc-crac.ca/english/codes_of_practice/factsheets/PIGS.htm.

There are now major concerns about the continuous close confinement of breeding females in cages or tether stalls. Pigs kept in such systems, alternating with farrowing crates during late gestation and lactation, are unable to exercise regularly for the whole of their reproductive life. Some studies indicate that sows kept in neck-tethers show a chronic physiological stress response, increased aggression between adjacent animals, and some evidence of changes in social behavior compared with group-housed pigs (Barnett et al, 1985). Animal welfare concerns are just beginning to surface, and it behooves animal scientists, veterinarians, and others involved in the swine industry to become involved in the investigations of and solutions to these concerns.

The aims of modern pig rearing are directed toward constant improvement of productivity. The resulting rearing conditions are more and more removed from the original way of life of the wild animal. The fundamental characteristic of wild boar and feral hog populations is their great adaptability to environmental conditions. This characteristic permits the use of a large range of rearing systems, extensive or intensive, to which the species can adapt.

There is growing worldwide concern for the welfare of pigs raised intensively in total confinement. Some countries have enacted legislation that states the minimum housing and management requirements. These minimum requirements include the following:

1. The possibility of being able to stand up or lie down in a manner characteristic of the species and to adopt a relaxed position (e.g., lying on their side with stretched limbs). This necessitates sufficient space.
2. During the rearing period, young animals should be given enough space to satisfy their instinct of play (e.g., running, fighting). This requires a suitable floor.
3. The floors of stalls or pens should allow the animals to tread and stand safely and to lie down without suffering injury. Perforated floors do not always fulfill these demands. Therefore at least the resting area should be bedded with a material like straw. Dry straw is an irresistible attraction to any pig, because it occupies and distracts the animals. Behavioral disturbances such as ear chewing or tail biting may be reduced by the presence of straw. Bedded floors also decrease the need for high ambient temperatures.

4. A restricted feeding system requires sufficient space for each animal at the trough. Care should be taken that the animals disturb each other as little as possible when feeding.
5. To avoid placing individual animals at disadvantage, they should be kept in groups of uniform sizes.
6. The animal's environment (or microclimate) must be appropriate for its particular age group.

The welfare of the intensively reared pig, its environment, and the incidence of disease are interrelated. Sows kept in confinement are exposed to more stress factors than sows kept free in pens. A definite relationship has been shown between herd size and increased frequency of toxemic agalactia, traumatic injuries in sows, piglet morbidity, and mortality. The health of litters in pens with straw as bedding was superior to that of litters in pens with other bedding materials. Litters in pens without bedding showed the poorest results. Herds in houses with liquid-manure handling systems were associated with poorer pig health than those with solid-manure handling systems. Postlactational anestrus was seen more frequently in sows confined in individual stalls compared with those free in pens.

TYPES OF SWINE PRODUCTION UNITS

Swine production units can be characterized as follows:

- *Farrow-to-finish.* Produces pigs through its sow herd and rears the pigs through to market at approximately 100 kg of live weight on the same site. This is a classical method of rearing pigs and is restricted in size and opportunities for disease control.
- *Farrow-to-feeder.* Produces pigs up to approximately 25 kg of body weight, at which time the pigs are sold or removed from the site to a growing-finishing unit.
- *Farrow-to-weaning.* Produces pigs that are sold or removed to the weaning to finishing site at time of weaning. Normally these pigs are weaned before 21 days of age to afford some level of disease control.
- *Growing/finishing.* Receives pigs from a farrow to feeder operation and markets them at a targeted body weight of 100 kg or greater.
- *Wean-to-finish.* Receives pigs from a farrow to wean unit and markets the pigs at a targeted weight of 100 kg or greater.
- *Breeding stock herds.* Specialized swine units that produce breeding stock. Multipliers are those that produce gilts for commercial pig units. Grandparent or great-grandparent herds produce pigs to populate the multiplier herds. Boar studs produce semen to be used for AI within the commercial units.
- *Segregated early weaning units.* There is a need to also differentiate swine herds based on the ability to control disease. A major change in pig production has been to introduce the concept of segregated early weaning (SEW) and AIAO production. SEW means that the progeny of sows are removed from the site to another rearing site—either the nursery or the wean to finish barn. All-out-out production means that before a new group of pigs enters the facility, the facility is cleared of all pigs and is thoroughly cleaned. In most cases the facility is a barn; however, for some diseases, all-in, all-out production is much more effective if the entire site is cleared of pigs. The combination of these two strategies has been called high health production, although it is often a misnomer. It has allowed for increased scale of production and has fit in well with contract production (Amass, 1998). It should also be emphasized that the best method of infectious disease control is the absence of the pathogen. Prevention of entry is through the selection of stock and control of fomites.
- *Contract finishing units.* Contract production is common in poultry production; however, it has only recently become common in swine production. In contract production the contractee normally provides facilities and labor to rear pigs. In many cases the owner of the pigs owns or manages the sow units and then contracts various producers to rear the pigs in nurseries' grow-finish units or wean-to-finish units. Normally these units are operated on an AIAO basis.

TARGETS AND CURRENT LEVELS OF PERFORMANCE

It has been said that "the way you manage and exchange information and the way you learn as a company are your only sustainable advantages" (Friedman, 1999). This is certainly true for today's pork producers. There are four key steps for monitoring performance:

- Rank the parameters being measured to define the key drivers at this farm that need close attention (a driver is a strong motivating force or stimulus)
- Benchmark periodically (e.g., quarterly for reproduction) among other herds within and outside the system (benchmarking is a standard for comparison, usually over a certain period)
- Monitor these drivers on a regular basis to ensure that the business is performing as expected
- Set goals for the key drivers and establish management plans to achieve them

Performance benchmarking is done to understand how a farm is performing relative to other farms. The objective is to understand those practices that will provide a competitive advantage. The process is to analyze the strengths and weaknesses of a farm's work processes, know the competition and industry leaders to determine who is the best, incorporate the best practices, and gain superiority to become the new benchmark.

The PigCHAMP database is commonly used for benchmarking (Table 15-1). Average 1-year values for breeding herd performance from the 1999 PigCHAMP database are listed in Tables 15-2 to 15-4. Table 15-2 is a summary of 1366 herds from seven countries, and Tables 15-3 and 15-4 are for U.S. and Canadian herds, respectively.

TABLE 15-1

PigCHAMP DataSHARE Participating Farms by Country (until November, 1999)

Country	No. of Participating Farms	Frequency (%)
Australia	1	0.1
Brazil	10	0.8
Canada	363	26.5
Japan	93	6.8
Korea	25	1.8
Mexico	19	1.4
United States	855	62.6
Total	**1366**	**100**

TABLE 15-2

PigCHAMP Breeding Herd Crude Summary (1999)

Measurement	Average	Median	Upper 25%	Upper 10%
BREEDING PERFORMANCE				
Repeat services (%)	12.9	12.6	8.7	5.7
Multiple matings (%)	84.5	92.6	97.6	99.4
Entry-to-service interval (days)	41.0	36.7	23.5	15.3
Sows bred by 7 days (%)	84.1	86.1	90.6	94.4
Weaning-to-first-service interval	7.7	7.1	6.2	5.4
Average nonproductive days	80	73	58	47
FARROWING PERFORMANCE				
Average gestation length	115	115	115	114
Average parity of farrowed sows	3.2	3.4	3.9	4.3
Farrowing interval	148	147	143	141
Farrowing rate (%)	77.3	78.5	83.3	86.8
Average total pigs/litter	11.2	11.2	11.6	12.0
Average pigs born alive/litter	10.2	10.2	10.6	10.9
Average stillborn pigs	0.8	0.8	0.6	0.5
Average mummies/litter	0.2	0.2	0.1	0
Percent <7 born alive	11.6	11.3	8.9	7.1
Preweaning mortality for farrowed and weaned	12.3	11.8	10.0	8.0
Litters/female/year	2.10	2.18	2.30	2.38
Litters/mated female/year	2.29	2.33	2.43	2.50
Old litters/mated female/year	2.25	2.33	2.44	2.54
Litters/farrowing crate/year	14.0	13.5	15.7	18.2
WEANING PERFORMANCE				
Pigs weaned/litter weaned	9.0	9.1	9.5	9.9
Average age at weaning	19.2	18.7	16.8	15.3
Adjusted 21-day litter weight (lb/kg)	128/57	128/57	137/62	146/66
Pigs weaned/sow	8.9	8.9	9.3	9.7
Pigs weaned/ mated female/ year	19.8	20.6	22.2	23.6
Old pigs weaned/mated female/year	20.6	21.0	22.9	24.6
Pigs weaned/female/year	18.5	19.3	21.0	22.5
Pigs weaned/lifetime	31.1	32	41	50
Pigs weaned/farrowing crate/year	125	122	140	165
POPULATION				
Average female inventory	662	380	857	1531
AFI/farrowing crate	6.7	6.4	7.3	9.0
Average gilt pool inventory	44	28	62	112
Sow:boar ratio	27	21	37	53
Average parity	2.6	2.6	3.1	3.6
Replacement rate (%)	54	50	39	29
Culling rate (%)	43	41	32	26
Death rate (%)	5.8	5.1	3.4	2.0
Average parity of culled sows	3.5	3.7	4.7	5.6

Farm n = 1366; median is a 50th percentile.

The 1998-1999 PigCHAMP growing-finishing database included 17,912 groups from 268 producers (Tables 15-5 to 15-8). The data were extracted from the PigCHAMP database on a group basis. The producers were located in Canada, Mexico, and the United States. Six conventional measurements for growth performance were calculated as follows:

- Average initial weight (Weight In): average weight when a group is placed in a location
- Average final weight (Weight Out): average weight when a group is moved to market or other location
- Mortality: included dead and destroyed pigs
- Average daily gain (ADG): includes only live pigs

TABLE 15-3

PigCHAMP Breeding Herd Summary in the United States (1999)

Measurement	Average	Median	Upper 25%	Upper 10%
BREEDING PERFORMANCE				
Repeat services (%)	14.1	13.8	10.1	6.9
Multiple matings (%)	86.6	92.3	97.1	99.0
Entry-to-service interval (days)	42.9	39.8	26.1	16.3
Sows bred by 7 days (%)	83.0	84.9	89.8	93.4
Weaning-to-first-service interval	7.8	7.2	6.3	5.5
Average nonproductive days	86	77	64	53
FARROWING PERFORMANCE				
Average parity of farrowed sows	3.1	3.2	3.7	4.1
Farrowing interval	147	146	143	140
Farrowing rate (%)	76.4	77.4	82.0	85.1
Average total pigs/litter	11.1	11.2	11.5	12.0
Average pigs born alive/litter	10.1	10.1	10.5	10.8
Average stillborn pigs	0.8	0.8	0.7	0.5
Average mummies/litter	0.2	0.2	0.1	0.1
Percent <7 born alive	12.2	11.9	9.9	8.2
PWM for farrowed and weaned	12.4	12.0	10.3	8.5
Litters/female/year	2.08	2.17	2.29	2.37
Litters/mated female/year	2.31	2.35	2.44	2.51
Old litters/mated female/year	2.30	2.35	2.45	2.54
Litters/farrowing crate/year	14.6	14.3	16.0	18.1
WEANING PERFORMANCE				
Pigs weaned/litter weaned	9.0	9.0	9.4	9.8
Average age at weaning	18.0	17.7	16.1	14.9
Adjusted 21-day litter weight (lb)	126	125	134	143
Pigs weaned/sow	8.8	8.8	9.2	9.5
Pigs weaned/mated female/year	19.5	20.4	21.9	23.2
Old pigs weaned/mated female/year	20.8	20.9	22.7	24.2
NPPC pigs weaned/mated female/year	19.0	19.7	21.5	23.0
Pigs weaned/female/year	17.9	18.9	20.4	22.0
Pigs weaned/lifetime	27.7	29.0	36.0	43.5
Pigs weaned/farrowing crate/year	130	127	143	164
POPULATION				
Average female inventory	964	635	1277	2208
AFI/farrowing crate	7.0	6.7	7.4	9.0
Average gilt pool inventory	59	47	86	132
Sow:boar ratio	31	28.4	43	57
Average parity	2.4	2.4	2.8	3.4
Replacement rate (%)	57.3	54.0	42.6	30.5
Culling rate (%)	45.0	43.0	32.9	25.8
Death rate (%)	6.8	6.3	4.1	2.6
Average parity of culled sows	3.1	3.2	4.2	5.0

Farm n = 658; median is a 50th percentile.

- Average daily feed intake (ADFI): uses only live pigs
- Feed conversion (FC): contains only live pigs (feed conversion is feed:gain ratio).

For presentation, the data were divided into four groups based on closing weights: <66 lb, 66-220 lb, >220 lb, and wean-to-finish. Table 15-5 is the first group (nursery with <66 lb close out); Table 15-6 is growing groups with >66 and <200 lb; Table 15-7 is finishing groups (>220 lb), and; Table 15-8 is wean-to-finish groups.

ECONOMICS OF PIG PRODUCTION AND THE MAJOR CAUSES OF ECONOMIC LOSS

A complete farrow-to-finish enterprise is a major financial consideration. In the year 2000 the cost of establishing a 1000-sow unit ranged from $3000 to $6000 (U.S. dollars)/sow, including the cost of the breeding stock. The producer investing this sum of money is faced with high interest rates, fluctuations in the price of market pigs

TABLE 15-4

PigCHAMP Breeding Herd Summary in Canada (1999)

Measurement	Average	Median	Upper 25%	Upper 10%
BREEDING PERFORMANCE				
Repeat services (%)	11.6	10.8	7.6	5.1
Multiple matings (%)	85.9	94.4	98.4	99.7
Entry-to-service interval (days)	32.9	30.8	19.5	14.0
Sows bred by 7 days (%)	87.1	88.2	92.2	95.5
Weaning-to-first-service interval	7.1	6.7	6.0	5.3
Average nonproductive days	64	59	48	41
FARROWING PERFORMANCE				
Average gestation length	115	115	114	114
Average parity of farrowed sows	3.6	3.7	4.2	4.6
Farrowing interval	148	147	144	141
Farrowing rate (%)	80.1	81.0	86.2	88.3
Average total pigs/litter	11.2	11.2	11.7	12.0
Average pigs born alive/litter	10.4	10.4	10.7	11.1
Average stillborn pigs	0.7	0.7	0.6	0.5
Average mummies/litter	0.2	0.2	0.1	0
Percent <7 born alive	10.2	9.8	7.9	6.5
PWM for farrowed and weaned	11.9	11.5	9.2	7.6
Litters/female/year	2.20	2.25	2.34	2.40
Litters/mated female/year	2.33	2.35	2.43	2.50
Old litters/mated female/year	2.33	2.37	2.46	2.56
Litters/farrowing crate/year	14.1	13.1	16.6	19.9
WEANING PERFORMANCE				
Pigs weaned/litter weaned	9.1	9.2	9.6	10
Average age at weaning	20.9	20.5	17.4	15.9
Adjusted 21-day litter weight (lb/kg)	61	62	65	73
Pigs weaned/sow	9.1	9.1	9.5	9.9
Pigs weaned/mated female/year	20.7	21.3	22.8	24.2
Old pigs weaned/mated female/year	21.7	21.7	23.6	25.5
Pigs weaned/female/year	19.8	20.6	21.9	23.4
Pigs weaned/lifetime	37.0	39.0	48.0	54.0
Pigs weaned/farrowing crate/year	130	122	152	187
POPULATION				
Average female inventory	406	268	481	820
AFI/farrowing crate	6.5	5.9	7.3	9.4
Average gilt pool inventory	24.0	11	29.1	59
Sow:boar ratio	24.0	19.7	30.5	47.3
Average parity	3.0	3.0	3.4	4.0
Replacement rate (%)	49.9	47.2	36.1	29.1
Culling rate (%)	41.1	38.9	32.3	25.4
Death rate (%)	4.7	4.3	2.7	1.5
Average parity of culled sows	4.2	4.5	5.4	6.1

Farm n = 292; median is a 50th percentile.

because of the pig cycle, and cash flow requirements to operate the enterprise.

The level of profitability in pig production is largely determined by the relationship of feed and market hog prices. On average, feed forms about 75% of total costs for farrow-finish herds but ranges from 65% for breeding herds selling weaners to 85% for feeding only herds that buy in weaners. Feed prices usually increase at a greater rate per year than pig prices; consequently, gross and net margins have usually been small, and a change in feed prices without a corresponding change in pig prices will affect profit margins. Total feed cost per hundredweight (100 wt) of pork produced is the product of the rate of feed conversion (e.g., 100 wt of feed/100 wt of gain) and the average cost per 100 wt of feed of all the feedstuffs used. There

TABLE 15-5

PigCHAMP Nursery Performance (1998-99)

Item*	Mean	SD	Percentiles 10%	25%	75%	90%
Weight in (lb)	12.0	3.7	9	10	13	15
Weight in (kg)	5.4	1.7	4.1	4.6	5.9	6.8
Weight out (lb)	45.0	13.7	22	38	55	61
Weight out (kg)	20.5	6.2	10.1	17	25	29
Mortality (%)	2.58	2.60	0.4	1.0	3.3	5.4
ADFI (lb)	1.25	0.43	0.7	1.0	1.4	1.7
ADFI (kg)	0.566	0.20	0.318	0.455	0.636	0.773
ADG (lb)	0.75	0.21	0.46	0.66	0.87	0.96
ADG (kg)	0.341	0.096	0.209	0.300	0.395	0.436
Feed:gain	1.68	0.35	1.36	1.50	1.80	2.02

ADFI, Average daily feed intake; *ADG,* average daily gain; *SD,* standard deviation.
*Group n = 6792 in 162 herds.

TABLE 15-6

PigCHAMP Grower Performance (1998-99)

Item*	Mean	SD	Percentiles 10%	25%	75%	90%
Weight in (lb)	29.2	25.8	10.2	11.8	45	63
Weight in (kg)	13.3	11.7	4.7	5.4	20.5	28.5
Weight out (lb)	122	59.5	67	71	192	214
Weight out (kg)	55.5	27.0	31	32	87	97
Mortality (%)	2.63	2.83	0.5	1.1	3.2	5.2
ADFI (lb)	2.88	1.39	1.5	1.7	4.1	4.9
ADFI (kg)	1.31	0.63	0.682	0.772	1.86	2.23
ADG (lb)	1.21	0.29	0.92	1.0	1.38	1.63
ADG (kg)	0.551	0.133	0.418	0.455	0.627	0.741
Feed:gain	2.30	0.75	1.57	1.72	2.84	3.30

ADFI, Average daily feed intake; *ADG,* average daily gain; *SD,* standard deviation.
*Group n = 1907 in 141 herds.

is as much variation in profit between producers as there is between the peaks and valleys of the hog cycles, which should persuade and convince producers, extension workers, and veterinarians to conclude that improved cost control and marketing practices have more potential for increasing profits than waiting for higher prices. The main factors that explain the variation in profitability among herds are the output (e.g., the number of pigs produced per sow in a herd each year) and feed (e.g., the quantity used and the price per unit).

The efficiency of feed conversion in the swine herd depends on the following:

1. Reproductive efficiency of the sow, whose maintenance represents a substantial portion of the total feed budget
2. Disease control, including clinical and subclinical disease
3. Feed wastage
4. Energy-expensive excessive fat carried by market pigs

Pig producers have increased production steadily by increasing the number of pigs weaned per sow per year and by improving feed conversion. A major contribution to containing production costs, however, has been the forced reduction in labor costs. Economic conditions have forced the pig industry to dispose of any surplus labor, and those that remain employed have increased their productivity.

In order to maintain financial viability, the enterprise must achieve certain production objectives (e.g., targets of performance), such as a minimum number of pigs per sow per year. The points in the production cycle that are most critical and vulnerable and that affect the number of pigs produced per sow per year and in turn can cause major economic losses include the following factors:

TABLE 15-7

PigCHAMP Finisher Performance (1998-99)

Item*	Mean	SD	Percentiles			
			10%	25%	75%	90%
Weight in (lb)	56.9	32.3	17.7	42.3	66	80
Weight in (kg)	25.9	14.7	8.0	19.2	30	36
Weight out (lb)	250	15.7	230	239	258	271
Weight out (kg)	113	7.1	103	109	117	123
Mortality (%)	3.12	2.52	0.8	1.6	4.0	6.0
ADFI (lb)	4.88	0.76	4.0	4.5	5.3	5.7
ADFI (kg)	2.22	0.35	1.82	2.0	2.41	2.59
ADG (lb)	1.58	0.23	1.34	1.46	1.71	1.83
ADG (kg)	0.719	0.104	0.609	0.664	0.777	0.832
Feed:gain	3.09	0.44	2.65	2.83	3.31	3.57

ADFI, Average daily feed intake; *ADG*, average daily gain; *SD*, standard deviation.
*Group n = 6342 in 197 herds.

TABLE 15-8

PigCHAMP Wean-to-Finish Performance (1998-99)

Item*	Mean	SD	Percentiles			
			10%	25%	75%	90%
Weight in (lb)	10.8	0.86	9.8	10.1	11.4	11.8
Weight in (kg)	4.89	0.39	4.5	4.6	5.2	5.4
Weight out (lb)	239	19	219	225	252	267
Weight out (kg)	108	8.5	99	102	115	121
Mortality (%)	3.68	2.4	1.4	2.0	4.7	6.7
ADFI (lb)	3.78	0.49	3.3	3.5	4.0	4.4
ADFI (kg)	1.72	0.22	1.50	1.59	1.82	2.0
ADG (lb)	1.40	0.27	1.26	1.33	1.43	1.49
ADG (kg)	0.635	0.12	0.573	0.605	0.650	0.677
Feed:gain	2.76	0.31	2.45	2.61	2.92	3.11

ADFI, Average daily feed intake; *ADG*, average daily gain; *SD*, standard deviation.
*Group n = 389 in 38 herds.

- *Reproductive performance.* A decrease in farrowing rate and a drop in the number of pigs born alive can cause major economic losses because of lost opportunity of profit. Every economic effort must be made to achieve and maintain the birth rate at between 10 and 11 pigs born alive/litter.
- *Neonatal mortality.* The greatest losses in pigs born alive occur during the first 3 days of life. Preweaning mortality may reach 20% to 25% but can be reduced to below 10% with good management and adequate farrowing area management.
- *Number of pigs weaned per litter.* The number of pigs weaned per litter is a function of the number of pigs born alive per litter and the preweaning mortality. An increase in the number of pigs weaned per litter from eight to nine in a 2400-sow unit means over 4800 extra pigs weaned/year.
- *Feed efficiency in pigs from weaning to market.* A major cause of economic loss during the growing and finishing periods is the inadequate level of feed efficiency. The presence of subclinical and clinical diseases affects feed efficiency. Suboptimum performance will occur because of overstocking in feeder pens, inadequate ventilation, and tail-biting.
- *Average daily gain.* As growth rate increases, more kilograms of pork will be produced in the same growth period. Although production costs and market prices will dictate the optimum market weight for a farm, most farms can increase profit by increasing rate of gain. Similarly, if disease is reducing daily gain, average weight at market

will usually be less, again because of the limited capacity for growing pigs at the farm.

- *Specific infectious diseases.* The economic losses resulting from specific infectious diseases are due to mortality, the cost of treatment, and the loss of potential production. The magnitude of the economic losses associated with the common diseases of pigs has been estimated and is described in the following text.

On an industry-wide basis, the economic losses associated with disease in pig production include the cost of veterinary fees, laboratory diagnosis, and medicines; the cost of the resources incorporated in breeding and other pigs, which are not recovered; and the resources used that are not recovered in the course of production. An overall reduction in mortality would enable the present level of output to be achieved with a smaller breeding herd, and there would be substantial savings in feed costs. A simple model for calculating the macroeconomic effect of improving livestock efficiency through better herd health such as reducing preweaning mortality in swine herds indicates how consumers gain from improved animal health (Ott et al, 1995).

The economic losses associated with condemnation of pig carcasses at slaughter because of the presence of disease that renders the meat unfit for human consumption is estimated at about 0.5% of all pig carcasses.

Subclinical Disease and Inadequacies of Management

Although the previous information on the costs of clinical disease is interesting and provides some clues about the nature of the diseases that concern producers, the causes and the magnitude of the economic losses associated with subclinical disease and inadequacies in management in swine herds are not known. It is probable that these losses are greater than those associated with clinical disease. There are a number of health and fertility problems that are generally present in a swine herd but vary greatly in degree, frequency, and severity among farms (Dijkhuizen, 1989). Often the individual farmer can do much to control or manage these problems. Identification of the economic impact of these problems, however, is not simple, because their effects are not always obvious. They are influenced by management factors such as housing and nutrition; they have a temporal dimension that adds to the complexity of evaluating their economic impact at different stages in time; and they commonly manifest in a complex with other diseases. It therefore is easy for producers to underestimate the economic impact of these problems, especially when they become accustomed to the presence of such problems. For example, weaning pigs older than 3 weeks of age, on average, has an adverse affect on sow productivity per year. A survey of productivity and its component interrelationships in Canadian swine herds revealed a wide range among farms in sow productivity, in growing-finishing efficiency, and in the efficiency of resource use (Wilson et al, 1986). Larger herds made better use of available physical resources, as indicated by the greater number of pigs weaned per farrowing crate per year and the greater number of feeder pigs marketed per square meter of feeder pen space per year. They also tended to have greater biological efficiency, as indicated by the greater number of pigs weaned per sow per year. The study suggested that a significant number of swine producers may be underutilizing both their capital and their human resources. By measuring the productivity gap, the study indicated the great potential that exists in the industry for increasing the efficiency of swineherds.

The further extension of swine health and production management techniques that are already in place in efficient herds should cause an increase in efficiency of pig production. The economic impact of these inadequacies in management can be determined using a variety of techniques, and the costs and benefits of control can be determined directly on the farm or by economic modeling (Dijkhuizen, 1989). For example, there is growing evidence that swine producers are losing income by culling sows when they are too young. Calculations for conditions that are typical in the United States indicated an economic optimum of 10 litters in a life span for sows of average productive performance, and young sows with a litter size of even 50% below average should not be culled before their third litter. A microcomputer program called PorkCHOP can predict the benefits of increased life span for sows and can help producers make economically sound decisions about culling sows with poor productive or reproductive performance (Dijkhuizen et al, 1986).

VETERINARIAN IN SWINE HEALTH AND PRODUCTION MANAGEMENT

The veterinarian in the swine industry has three main roles: the diagnosis and treatment of individual animals; the diagnosis and treatment of groups of animals or whole herds; and the provision of advisory services to the farm to improve production, health, and productivity. The first role is diminishing, and the third role is increasing (Muirhead, 1996). The changing roles are a reflection of the ever-changing swine industry. The number of herds is decreasing, and the size of herds is increasing. One view is that the general practitioner can handle most problems in herds with up to 150 sows. In herds larger than this, a specialist's knowledge of the swine industry and herd is necessary. The very large swine producer or farming company with herds of 500 to 1000 sows requires the services of a veterinarian who can deal with the complex interrelationships that exist in such large herds. The characteristics of the large swine producer of the 1990s include the following: they produce over 500 litters/year; it is a family farm; the second-generation members of the family have college degrees; the family is hard working, conservative, quite wealthy, and has several employees; the farm is also involved in the production of crops; and the producer takes risks (Vinson, 1986).

There has been a gradual increase in demand for consultancy veterinary services and a marked decrease in emergency type visits. In the United Kingdom, the veterinarian/sow ratio in 1996 was considered stabilized at 1/15,000 sows (Muirhead, 1996).

Veterinarians can have an economically viable practice from large swine farms through the sale of drugs, vaccines, other animal health supplies, and premixes; veterinary services; and consultation (Vinson, 1986). Because of competition from other sources, the revenue from the sale of drugs and vaccines is limited. Veterinary services include the routine diagnosis of disease, writing of prescriptions, government regulatory work, acute disease drug therapy, and specialized surgery. The consultation services consist of helping producers with intermediate and long-term decisions regarding disease management, cost-benefit nutrition, genetic program evaluation, environmental management, and the logistics of production flow of pigs.

In the study of the U.S. livestock market for veterinary medical services in 1994, swine practitioners generated the highest individual practitioner revenue and the highest percentage revenue from sales of animal health products (Wise, 1995).

Requirements for the Swine Specialist

How does the veterinarian acquire specialist expertise to provide service to these large sophisticated swine enterprises?

The requirements necessary to obtain specialist knowledge in a general farm practice modified according to Muirhead (1996) are listed in Box 15-1.

Education of the Swine Specialist

The education of the swine specialist begins at the undergraduate veterinary student level and continues with postgraduate studies and learned experience in a specialty practice. The undergraduate curriculum should provide the basic sciences, the paraclinical sciences, and the clinical sciences necessary for the student to learn the fundamentals of swine health and production. Species specialization before graduation is not possible and should not be attempted. A critical analysis of the undergraduate teaching of swine medicine in North American veterinary schools found a deficiency in the amount of time allocated to classroom and clinical teaching of swine medicine (Backstrom, 1989). Veterinary colleges should consider how to provide the basic classroom and clinical teaching in swine medicine to those students who are interested in pursuing swine practice. This can be done with quality elective courses and in-depth postgraduate courses. There is a need for a coordinated effort between swine practitioners, university faculty, swine producers, and consumers to consider ways and means of providing the appropriate undergraduate and postgraduate education required to produce swine veterinary specialists.

Postgraduate education and specialization in a species has been considered for many years. Graduate degrees in swine medicine are available from a number of veterinary colleges in the United States, including Iowa State and the University of Minnesota. Specialization in an area such as production-oriented swine medicine requires not only an increased understanding of the knowledge base in swine health and production but also practical experience on different swine farms with a variety of production problems. Veterinary colleges can usually supply the knowledge base but usually do not have sufficient clinical teaching practice. Some postgraduate clinical residency positions are available at veterinary colleges, but these are minimal in number. Self-directed learning in a specialty practice is the alternative option for those wanting to become pig specialists. This can be done on an individual basis, with the addition of several-day short courses and workshops in swine health and production management. This self-directed learning in practice can be followed by certification by examination, which is now possible in the United Kingdom through the Royal College of Veterinary Surgeons. There are currently two levels of examination. The certificate should be attainable by any veterinary graduate who has been working regularly in the treatment and control of pig diseases for at least 2 years beyond graduation. The certification covers the same subjects in more depth and breadth and is for the veterinarian who has worked the equivalent of 5 years in pig practice and who has acted as a consultant in major pig problems (Muirhead, 1996). Studying for the examinations concentrates veterinarians on pig production and medicine, with an emphasis on the interaction between health and production of the herd. It requires considerable self-motivation and self-education to achieve specialty status, and the most important requirement is the development of the correct organizational framework within the practice to satisfy the necessary details listed in Box 15-1. Swine specialization must be learned in practice after graduation.

BOX 15-1

Professional Requirements of Swine Veterinary Specialist

- Practice in a species-specialist veterinary practice
- Access to a veterinary practice library with visual aids
- Access to a veterinary college library when necessary
- Availability of farming publications
- Membership in a swine specialist society
- Participation in a continuing professional development program 14 days annually
- Good foundation in individual animal medicine
- Good laboratory facilities that can provide rapid service
- Practice policy of continuing specialized education
- Ongoing teaching by specialists in the practice
- Regular time periods for case studies
- Computer literate and able to use appropriate software programs for swine production
- Provisions for studying and analyzing farm reports
- Studies to understand farm management in depth
- Organized workload
- Preparation of papers and case reports
- Preparation and delivery of seminars at the farm level
- Good internal practice liaison
- Access to research and knowledge of development and economics of production
- Graduate education, (e.g., MS and/or Ph.D.)
- Board certification (American Board of Veterinary Practitioners or similar certification boards in other countries)
- Fluent understanding of Spanish
- Access to a laptop computer for on-farm use
- Ability to interpret production and financial data

Providing Veterinary Service

The provision of a health and production management veterinary service to swine herds requires commitment from the veterinarian and the veterinary practice to develop the specialty. The veterinarian must be interested in acquiring the knowledge and skills necessary to provide the service, and the practice must allow the veterinarian to schedule blocks of time to visit swine farms, become thoroughly acquainted with all aspects of production, and consider the health and production records in detail (Straw and Friendship, 1986). The veterinary practice must have the technical and secretarial staff necessary to assist the veterinarian in scheduling visits, ordering supplies, entering data into the computer, preparing reports, and other routine activities associated with providing such a service. The scheduling of farm visits must be done well in advance, and every effort must be made to adhere to the schedule; this necessitates excellent communication and the flexibility to meet unforeseen circumstances.

The success of a health and production management veterinary service depends heavily on the compliance of the producer. The producer may not have confidence in the veterinarian as a health management advisor; the veterinarian may overwhelm the producer with too many recommendations at once; the veterinarian may not be aware of the client's expertise or financial constraints; and there may be a failure of communication between the veterinarian and the

producer about the production goals for the herd and how they are to be achieved (Friendship, 1989).

Implementation of the veterinarian's recommendations requires time for the producer to appreciate their value, and the veterinarian must use certain strategies to gain their acceptance and make the recommendations in stages. It may take months for the producer to understand and appreciate new health and production techniques. Initially, the veterinarian should gain the confidence of the producer by attempting to solve an obvious but simple problem, then move to the more complex ones. The veterinarian must be aware of the financial constraints of the producer before making recommendations requiring major capital investments. The level of knowledge and the goals of the producer must be considered before making recommendations. Taking the time necessary to analyze and interpret the health and production records of the herd often motivates producers to take action to improve performance. Making interfarm comparisons of performance often activates the interest of producers on how they are doing relative to other anonymous producers. Consultation with other specialists can be effective in persuading a producer to consider certain recommendations for the solution of a problem. When producers appreciate that the techniques have been successful elsewhere, they will often consider adopting them much more quickly.

As swine production systems and the attitudes of producers towards the veterinarian have evolved, so has the means of charging for professional fees. Early efforts to earn a professional income from swine practice consisted of charging a specified fee for a given service, such as vaccinating or castrating pigs, or farrowing a sow. However, with time, producers learned some of these skills, and many of these services are no longer provided by veterinarians. This led to an emphasis on the sale of animal health products (antibiotics and vaccines), often coupled with free veterinary consulting services, or the development of hourly or daily herd health consulting fees. Ultimately, innovative charging methods developed that linked the practitioner's income with the success or failure of the producer, such as a certain dollar amount per pig weaned, according to the producer's production data. Other methods of income generation include annual fees on a "per head of breeding animal" basis, or an hourly fee for time spent on the farm and in preparation of reports in the veterinarian's office. Some swine specialists do international consulting as well as field trials for pharmaceutical and biological companies. Others are employed as full-time resident veterinarians within integrated firms.

Population-Based Problem Solving in Swine Herds

Swine practitioners providing health and production services must be systematic and comprehensive problem solvers who can understand and operate within the complex biological and economic systems that compose pork production. There is a need to provide proactive advisory services that control disease and manage the effect of disease in the herd. Population-based problem solving is an integral part of effective health management of a livestock operation. The first requirement is reliable information. In a swine herd, information is crucial to being able to diagnose problems in herd productivity. Effective problem solving in a swine herd requires production and financial data, as well as herd and animal specific demographic data, and reliable cost estimates (Polson et al, 1998). The data for a herd are made meaningful by establishing benchmarks for that herd and monitoring performance over a period of time. In this way a "performance-related diagnosis" can be made when "performance indicators" indicate unacceptable productivity. Production benchmarks (e.g., pigs weaned per female per year) quantify what is "normal" for a specific herd. Problems in a herd are indicated by a deviation in performance from what is expected or considered normal. The major challenge in population-based diagnosis is differentiating between the inherent variability normally expected in the herd and deviations from the benchmarks that represent "real "problems with productivity. Knowing the important risk factors that are related to each of the various diagnostic indicators allows the problem solver to set priorities and plan interventions.

Swine Producer and Health and Production Management

Health management of swine herds emphasizes herd-level disease control and production analysis. Individual animal medicine emphasizes clinical examination of the individual animal using all the diagnostic and laboratory tests deemed necessary and economical in order to arrive at a diagnosis so that treatment and control can be provided. Health management of the herd involves examination of the herd using all available techniques, particularly record analysis, to determine the various levels of production, and the reasons for failing to achieve predetermined levels of production, and profit.

Producers who use swine veterinary specialists as regular consultants in a swine health management and production program are knowledgeable about swine production and are financially successful (Deen et al, 1995b). They are also the producers who are willing to take risks and are not financially overextended. Producers who have not adopted health management veterinary services usually do not appreciate the effects of subclinical disease, their primary goals do not include optimizing health and economic performance, and they do not maintain an effective recording system.

A comparison of producers who use regularly scheduled health management veterinary services with those who do not found that the following factors were positively associated (Deen et al, 1995b):

- Farms that were larger, had more leverage financially, and used record-keeping and modern nursery technologies employed veterinarians. Herds with a debt level of more than 50% were 1.87 times more likely to use the service. Herds that kept records were 3.5 times more likely to use the service.
- Number of pigs marketed annually. Herds with annual sales of more than 1000 pigs were 1.58 times more likely to use health management services.
- Use of slatted floors in the nursery.
- Washing of floors in the nursery.
- Farms that primarily finished pigs were less likely to use the service.

In a survey of American swine producers, 49% reported veterinarians to be a very important source of herd health advice, whereas 37% considered veterinarians to be somewhat important (Wise, 1987).

MONITORING PRODUCTION AND DISEASE IN THE SWINE HERD

A successful swine herd health and production program depends heavily on a simple, reliable record-keeping system to monitor performance and incidence of diseases. A regular analysis and interpretation of the records combined with a regular clinical examination of the herd—including necropsy examination of pigs that die naturally or

of selected sick pigs—allows the veterinarian to identify problems that are interfering with production and to institute corrective measures. Records define the levels of achievement in the herd and thereby outline the need for change or improvement. It is essential, however, that the information recorded be consistently meaningful. The information can be used to determine whether productivity is being maintained at a predetermined level or if fluctuations are occurring in any particular parameter over a period of time.

Records alone, however, are not enough to identify the problems, and a clinical examination of the herd is essential. Once established, the recording system and data analysis will indicate the actual performance in that herd, which can be compared with predetermined targets. These levels may be ultimate standards, which will not be improved with existing knowledge, or standards defined at selected points in an improvement program.

Terms and Definitions

Animal production recording systems require precise definition of the various classes of animal identified and the periods of time measured. There is no comprehensive list of the terms and definitions used in pig recording. In the past, production recording systems have relied on undefined terms, and as a result, the same classes of pigs may be described in different ways. The U.S. NPPC (1999) published a "Production Standards Technical Manual" with suggested definitions and equations for all software providers. The intent is to give producers the ability to compare production and financial performance even when they use different software. Their definitions, suggested comparison indexes, and methods of calculation are very similar to traditional methods, but a few marked differences exist. First, the manual suggests that all pork production systems comprise one or more distinct phases or stages, including breeding stage (including gestation and farrowing), nursery production, and finishing production. Second, it is suggested that all female pigs intended for breeding be classified in one of four categories, with the transition between categories being driven by the occurrence of events in the female's life history record:

- *Prospective breeding female:* a female pig kept for the purpose of future entry into the breeding herd.
- *Unmated breeding female:* a female pig entered into the breeding herd but not yet mated.
- *Mated breeding female:* a female pig mated at least once and not yet removed from the breeding herd.
- *Removed breeding female:* a breeding female that is no longer consuming assets or resources of the breeding herd.

Third, growing pigs are classified as preweaned pigs (triggering event being the farrowing), nursery pigs (pigs moved into a nursery facility), or finishing pigs (pigs moved into a finishing facility). Fourth, they recommend that the term litter be classified as birth litter, wean litter, or nurse litter. Fifth, they define and recommend the use of the term *cohort* as a group of animals that share a common event within a defined period. A cohort can be a group of mated breeding females or a group of finishing pigs placed in a finishing facility within a defined time period. And finally, they recommend that all inventory calculations should be on a pig-day basis, in which a pig-day is defined as one live pig for 1 day, counted at the end of the day.

The recommendations just described are being used by some software providers to offer additional reports that will allow their users to compare performance across software products. As data accumulate, practitioners will be able to establish benchmarks with these new definitions. In the interim the traditional and still most widely used terms, as described below, continue to be accepted.

Breeding Herd

- *Sow:* Any breeding female that has been served and is on the farm.
- *Maiden gilt:* A female transferred to the breeding herd but not yet mated.
- *Boar:* A male pig older than 6 months of age and intended for use in the breeding herd.
- *Sow cull:* Any live sow removed from the farm.
- *Boar/sow ratio:* The ratio of boars to sows as defined above. Any definition must take into account the nonworking boar.
- *Herd size:* The average number of sows present in the herd as recorded on 12 or more equally spaced occasions during a year.

Fertility Data

- *Service:* One or more completed and recorded matings within the same estrus period.
- *Date of service:* Date of the first mating during any one estrus period (counted as Day 0).
- *First litter sow:* A female pig between the date of first effective service (i.e., a service that results in pregnancy) and the date of the next effective service after successful completion of pregnancy.
- *Farrowing:* Production of a litter of one or more live or dead pigs on or after Day 110 of pregnancy; day of service is Day 0 (see explanatory note 1 in the following section).
- *Farrowing rate:* The number of sows that farrow to a given number of services expressed as a percentage.
- *Induction:* The use of a drug that is capable of inducing farrowing. Usually used from 1 to 3 days before the expected farrowing date to synchronize the farrowing of a number of sows on the same day.
- *Conception rate:* The number of sows that conceive to service, expressed as a percentage of these services. Conception is assumed by nonreturn to estrus 21 days after service or identified by pregnancy diagnosis. This measure is not precise, and the term is therefore of limited use.
- *Return to service:* A sow re-served after a return to service.
- *Regular return:* A return to service 18 to 24 days after the date of service (see note 2).
- *Irregular return:* A return to service outside the 18- to 24-day period after the date of service (see note 2).
- *Herd farrowing index:* The number of farrowings taking place in 365 days divided by the average number of sows in the herd during that period, as defined in the last section for *herd size*.
- *Weaning date (sow):* The date on which a sow ceases to suckle piglets.
- *Weaning-to-service interval:* The interval between date of weaning and the date of first service (date of weaning is Day 0; see note 3).
- *Nonproductive days:* Nonproductive days are average number of that a sow or gilt is not lactating or gestating (see note 9).
- *Abortion:* The observed production of fetuses between service and up to and including the 109th day of pregnancy, when none of the fetuses survive more than 24 hours (see note 1).
- *Premature farrowing:* The observation of fetuses before the 110th day of pregnancy, when some fetuses survive for more than 24 hours (see note 1).
- *Failure to farrow:* Sow not farrowed by 120 days after a presumed effective service.

Progeny: Preweaning Period

- *Litter:* The production of a farrowing.
- *Number of piglets per litter:* The total number of piglets born per litter, including stillborn and mummified pigs.
- *Live-born piglets:* Piglets that are born alive.
- *Stillborn piglets:* Piglets found dead behind the sow farrowing; if necessary, perform postmortem examination to determine if the piglets have breathed.
- *Mummified piglets:* The number of dead piglets that are born degenerate (e.g., discolored and shriveled), which means they died some time before farrowing.
- *Premature pigs:* Piglets born alive before the 110th day of pregnancy and surviving for more than 24 hours (see note 1).
- *Small litter index* (sometimes referred to as *litter scatter*): The percentage of litters born within any specified period in which the number of piglets in any litter (see *number of piglets per litter*) falls below x, where x is the nearest whole number lower than 1 standard deviation (SD) below the mean number of piglets per litter (see note 4).
- *Live birth weight of litter:* The total weight of piglets alive at birth or who have survived the first 24 hours of life (see note 5).
- *Suckling pig or piglet:* Piglet between birth and weaning.
- *Preweaning mortality:* The percentage of live-born piglets that die before weaning.
- *Fostering:* The transfer of piglets from one litter to another for management purposes. Fostering-on is the introduction of extra piglets, and fostering-off is the removal of pigs from a litter.
- *Weaning (piglets):* The act of permanently removing piglets from the sow.
- *Age at weaning:* The number of days from farrowing to weaning (day of farrowing is Day 0).
- *Herd weaning age:* The average number of days from farrowing to weaning for the herd.

Progeny: Postweaning Period

- *Nursery pig:* A weaned pig is a pig between weaning and either at the end of the stay in the nursery accommodation or 30 kg if it is to remain in the same accommodation until slaughter. Since pigs are weaned at vastly different ages, this definition can cover a wide age range.
- *Nursery mortality:* The number of nursery pigs that die expressed as a percentage of the total number of pigs in that group initially.
- *Feeder-finishing:* Any pig in the stage of life between the end of the nursery period and slaughter weight or the time of transfer to the breeding herd.
- *Pigs marketed:* Pigs marketed alive in any form or transferred to the breeding herd, not including sales from the breeding herd.

Feeder-Finishing Data

These are classes of finishing pigs that are categorized by weight. Different recording schemes and marketing systems use different weights (see note 6).

- *Live weight gain:* The live weight gain of the pig when sold minus its birth weight. If the birth weight is not available, it is counted as 1 kg.
- *Days to slaughter:* The age of a pig at slaughter is the number of days from the date of birth (Day 0) to the date of slaughter of that pig.
- *Daily live weight gain:* The live weight gain of a pig divided by the number of days between two weighings.
- *Feed conversion ratio (FCR):* The total weight of dry food consumed by a pig divided by its live weight gain (see note 8).
- *Feeder-finishing mortality:* The number of feeder-finishing pigs that die in a group expressed as a percentage of the total numbers of feeder-finishing pigs in that group initially.
- *Average days to slaughter:* The average number of days to slaughter for a group of pigs, excluding those that die.
- *Average weight at slaughter:* The average live weight at slaughter (see note 7).
- *Transit death:* A pig that dies in transit on the truck between the end of loading at the farm and the end of unloading at the abattoir or final disembarkation point.
- *Lairage death:* A pig that dies between the end of unloading at the abattoir and the point of slaughter.
- *Condemnation:* A carcass condemned wholly or in part.
- *Casualty-culls:* Any pig for which payment is received that is slaughtered on welfare grounds or for persistent slow growth.

Explanatory Notes on the Terms and the Definitions

1. *Gestation length:* This varies between herds according to breed and other factors, but data held at Weybridge that relate to a large body of accumulated information from British herds give a mean figure 114.5 days ± 1 SD 1.5 days. From this it can be said that the 95% confidence interval is 111.5 to 117.5 days.

2. *Estrous cycle length:* A review of all available information suggests a mean estrous cycle length of 21 days ± 1 SD 1.5 days. These figures give 95% confidence interval of 18 to 24 days, and this is the range that has been used for the calculation of regular and irregular returns.

3. *Weaning-to-service interval:* This depends on many factors, not the least of which is the length of lactation. Analysis of data from a variety of sources suggests that, for all practical purposes, a mean figure of 7.5 ± 1 SD 2.5 days is acceptable. The interval is variable because a wide range of factors (e.g., level of nutrition, disease status, management systems) affects it. But this figure is a satisfactory working guide in relation to weaning-to-service interval.

4. *Total litter size:* It must be clearly recognized that litter size is affected by a great many factors, including maternal age, breed, and disease status, and that it may vary from country to country. For the purpose of this book, some figure that can be regarded as characteristic of the British situation and the variability that occurs between individuals is given. For British herds the mean figure for litter size is 10.75 ± 3 piglets. It is from this figure that the small litter index (see term as defined above) is calculated (i.e., for the above figures, the small litter index is the percentage of litters that contains less than seven pigs).

5. *Piglet birth weight:* Some indication of the mean and variability of normal piglet birth weights may be useful, and data obtained from Weybridge and other sources indicate that the mean is 1250 g ± 1 SD 250 g.

6. *Values for slaughter pigs:* Values for different grades of carcasses.

7. *Herd values for slaughter pigs:* Herds do not operate under a system of production that identifies individual slaughter pigs. There are two methods of calculating growth performance. Smaller herds will often move pigs continuously through finishing facilities, and over time, estimates of performance can be calculated. More commonly, batches or groups of pigs are moved together and group record will be calculated for growth performance. The equations follow in entry no. 9.

8. *Feed conversion ratio:* On the farm, FCR estimates are required either for groups of pigs or for the whole finishing herd. If this is to be done accurately for any given period, it is necessary to record the weight of the feed in inventory at the beginning of the period, the weight of feed entering

inventory during the period, and the weight in inventory at the end of the period.

Similarly, it is necessary to know the weight of pigs in the group at the beginning and end of the period in question as well as the weight of the pigs entering or leaving the group during the period. This means that all pigs entering and leaving the group need to be weighed and that all the pigs in the group are weighed at the beginning and end of the recording period.

In the assessment of pig feed conversion efficiency as indicated by FCR, notes should be made regarding the nutritive density of the diet.

9. *Nonproductive days.* The number of nonproductive days gives an indication of the regularity or rhythm of a herd's breeding performance. The merit of this particular index is that it is easy to collect and gives a continuous indication of the regularity of breeding within the herd.

$$\text{Average weight of pigs sold} = \frac{\text{Total weight of sales} + \text{Total weight of transfers}}{\text{Number of sales} + \text{Number of transfers}} \quad [1]$$

$$\text{Average weight of pigs on entry} = \frac{\text{Total weight of purchases} + \text{Total weight of transfers in}}{\text{Number of purchases} + \text{Number of transfers in}} \quad [2]$$

$$\text{Total weight gain} = \text{Total weight of sales} + \text{Total weight of transfers out} + \text{End of period total weight} - (\text{Total weight of purchases} + \text{Total weight of transfer in} + \text{Start of period total weight}) \quad [3]$$

$$\text{Percent mortality} = \frac{\text{Deaths} \times 100}{\text{Number of sales} + \text{Transfers out} + \text{Deaths}} \quad [4]$$

$$\text{Feed conversion ratio} = \frac{\text{Total weight of feed consumed}}{\text{Total weight gain}} \quad [5]$$

$$\text{Daily live weight gain} = \frac{\text{Average weight gain/pig}}{\text{Average number of days in herd}} \quad [6]$$

$$\text{Average weight gain} = \text{Average weight of pigs sold} - \text{Average weight of pigs entering} \quad [7]$$

$$\text{Average days in herd} = \frac{\text{Average number of pigs in feeding herd} \times 30.4}{\text{Average number of sales and transfers out per month}} \quad [8]$$

Statistical Note

SD is a measure of the scatter of individual readings about the mean (e.g., average). Where values are normally distributed, approximately 66% of values will fall between 1 SD on either side of the mean, 95% within 2 SD, and 99% within 3 SD.

Identification of Pigs

Accurate identification of individual breeding females is essential for any comprehensive production recording system. Some form of permanent marking is required for performance assessment, herd security, disease surveillance, and quality control. Identification marks should be easy and painless to apply, legible at a distance, and tamperproof. At present, there is no single system that has all these attributes, the most common failing being the loss or illegibility of the identification mark well before the end of the animal's life in the herd. The methods commonly used include ear marking by notching, tattooing, or tagging, or body marking (e.g., slap marking). If animals destined for breeding purposes are to be identified correctly, experience suggests that the best system is tattooing supplemented by a large flexible plastic tag inserted in each ear when the pig enters the breeding herd.

Data Recording on the Farm

The following events and animal identities are the basis of a pig recording system. The amount of data will vary from herd to herd and depends in part on the facilities available.

Data Recorded in the Breeding Herd

- Sow identity
- Birth date or date of entry
- Service date and boar used
- Abortion date
- Farrowing date
- Number born alive
- Number born dead
- Number mummified
- Total litter weight at birth
- Piglet deaths (recorded as they occur)
- Weaning date and number weaned
- Weight at weaning (total litter or individual pigs)
- Weaner deaths (recorded as they occur)
- Sow culling date
- Feed consumed by breeding females and by piglets in nursery

Data Recorded in the Feeder-Finishing Barn

- Identity of group
- Date of entering nursery-feeder-finishing unit or date at which 30-kg live weight reached
- Group weight at entry
- Date sold off the farm
- Weight at date of sale
- Total amount of feed consumed to determine feed conversion ratio
- Death losses (recorded as they occur)

Methods of Recording Data

The events and animal identities just mentioned are recorded by the herdsperson. He or she may use a notebook to jot down observations as they are made, but these have to be transferred to some kind of record form. Record forms that are completed and kept in the piggery are called *barn records.* Record forms that are completed from notebook records or barn records but are kept in the farm office are called *office records.* Barn records or office records are used to calculate indexes of performance. The calculations may be carried out manually, in which case it is important that the barn or office records be kept in such a way that calculation of indexes requires the simplest possible manipulation of data. Calculations may also be carried out with the aid of computers. The calculation of indexes is a simple task for the computer and allows for the calculation of far more sophisticated indexes than is practical with a manual system.

Barn Records. Many different styles of barn records have been developed for use in the barn. The essential feature is that they allow the recording of the necessary data, which can then be extracted easily for the calculation of performance indexes. Regardless of the system used, it should be

simple and readily accessible to each herdsperson, the supervisor in the case of large herds, and the veterinarian. The records should be kept in a central location.

The minimum requirements for barn records include the following:

- Sow record card
- Daily diary or handheld data recorder
- Sow service card
- Daily record

Sow Record Card. This is also called the *litter card,* and it is essential that each sow has a record card that is kept with the animal. Normally these cards record events over one parity (e.g., weaning to weaning), although some sow records kept in the piggery contain a listing of events over the sow's adult lifetime. When the single parity record is complete, it can be stored in the office or can be used to complete a lifetime record. Sow cards may be clipped to the sow's stall and moved when the sow is moved from the dry sow area to the farrowing barn and back again to the dry sow barn. Sow cards should be covered with a piece of removable transparent plastic because they can become wet and soiled and difficult to read.

Daily Diary or Handheld Data Recorder. The daily diary is a useful technique for recording events throughout the day while the animal attendant is in the barn. The diary is pocket-sized and self-duplicating so that the duplicate copies may be collected regularly and the data posted directly into a computer bank. Handheld devices have the advantage of avoiding double data entry because they can transfer data directly to the record system at the end of the work day.

Sow Service Card. The service card records all service events, including returns to service. The service card is ideal for bringing into the office for copying onto office records or for the direct calculation of indices.

Daily Record Card. This is a register of events occurring over a 24-hour period. It should be completed at the same time each day and has two purposes: (1) it provides data for analysis by the veterinarian, and (2) it provides the herdsperson with a day-to-day summary of the productivity of the animals in the herd. Each card lasts 1 month and is kept on a clipboard. At the end of the month, the card is passed to the office, where monthly totals are calculated, and passed back to the herdsperson. This toting-up procedure is the simplest possible way of keeping a monthly record of events and is far easier than making calculations from individual sow cards. In the early stages of a recording system, irrespective of the size of the unit, a weekly module rather than a monthly module may be desirable. With experience, this can be expanded to a 28-day system, but a weekly summary will give the manager more information as the system becomes established.

Performance Records. Individual sow lifetime records are an extension of the single-parity record. The monthly herd performance record is an extension of the daily record. The herd performance report can be constructed with a minimum of manual computation from the barn records (e.g., sow card, service card, and daily event record). The herd performance report provides a record of all the main indexes of performance required, and it provides a ready comparison of present performance with the previous 6-month average as well as with a target figure set by the veterinarian. Sow reproductive performance according to parity also can be plotted as the sows farrow and summarized on a periodic basis.

Visual Sow Charts and Wheels. Breeding wheels and wall calendar charts have been in common use on pig farms for many years. They usually take the form of a large disc or fixed board or chart. These visual display systems are a simple but effective method of providing immediate information on the present and future position of sows in the breeding herd. They are not in themselves a data-recording system, since they do not provide a permanent record, and they are no substitute for accurate and complete barn and office records. They are management tools used on a daily basis to indicate to the herdsperson the flow of breeding animals through the herd. The system indicates to the herdsperson when groups of sows are due to be moved from the gestation barn to the farrowing barn in sufficient time for adjustment to occur. This avoids sows farrowing in the gestation barn. It also reminds the herdsperson to prepare for the weaning of a group of sows.

At a glance and on a daily basis, the sow breeding calendar wheel indicates the following information:

1. Expected date of farrowing of each sow, which allows the producer to transfer the sow to the farrowing crate several days before the expected farrowing date
2. Actual date of farrowing of each sow
3. Dates the pigs should be weaned and actual dates of weaning, which allow adequate preparation of nursery pens and weaning of most litters at about the same time
4. Date each sow should come into heat after weaning her pigs
5. Actual dates of heat and breeding
6. Number of times the sow was bred
7. The identity of the sows that have been diagnosed as pregnant

Computer-Based Recording Systems. Some form of manual recording system is adequate for a small herd, but as the size of the herd increases, the limitations of such a system become obvious. A computer system is capable of storing extensive records on large numbers of animals, and it easily manipulates complex sets of data that would be impractical to handle manually.

The need for computerized record systems for swine production data has led to a variety of sources, such as large mail-in service bureaus, on-farm computerized records, and in-practice systems as part of a health management service. The most common program used in the industry is called *PigCHAMP* and was developed at the University of Minnesota in 1985 (Stein et al, 1987; Stein, 1988). A continuous flow of production data is the cornerstone of health management services, and the computer can provide continuous analysis of the data. The computer provides assistance for problem solving at the herd level by determining any deviation between actual herd production (e.g., what is happening) and a target (e.g., what is expected to happen). Problem-oriented population medicine involves (1) production monitoring, (2) production analysis, (3) production reference values, (4) production targets, and (5) action plans. Production monitoring is the process of continually reviewing current production data to determine whether production targets are being achieved and to identify trends that may influence future planning and action (Stein, 1988).

Data Capture Sheets. The first step in recording is similar in both manual and computer-based systems: that is, recording of the initial observations. The initial observations are recorded on data capture sheets, which are used for direct entry into the computer. Examples of capture sheets are as follows (Figs. 15-3 to 15-8).

This step is labor intensive, and each time data are handled or transferred from one sheet to another, the number of errors increases. One way to minimize errors is to record the observations directly into an electronic notepad, which in turn reports directly to the computer.

Many organizations provide whole-herd recording systems, which depend on sending input to and receiving output from a central bureau. The emphasis in each system may be different. Some monitor the performance of the swine

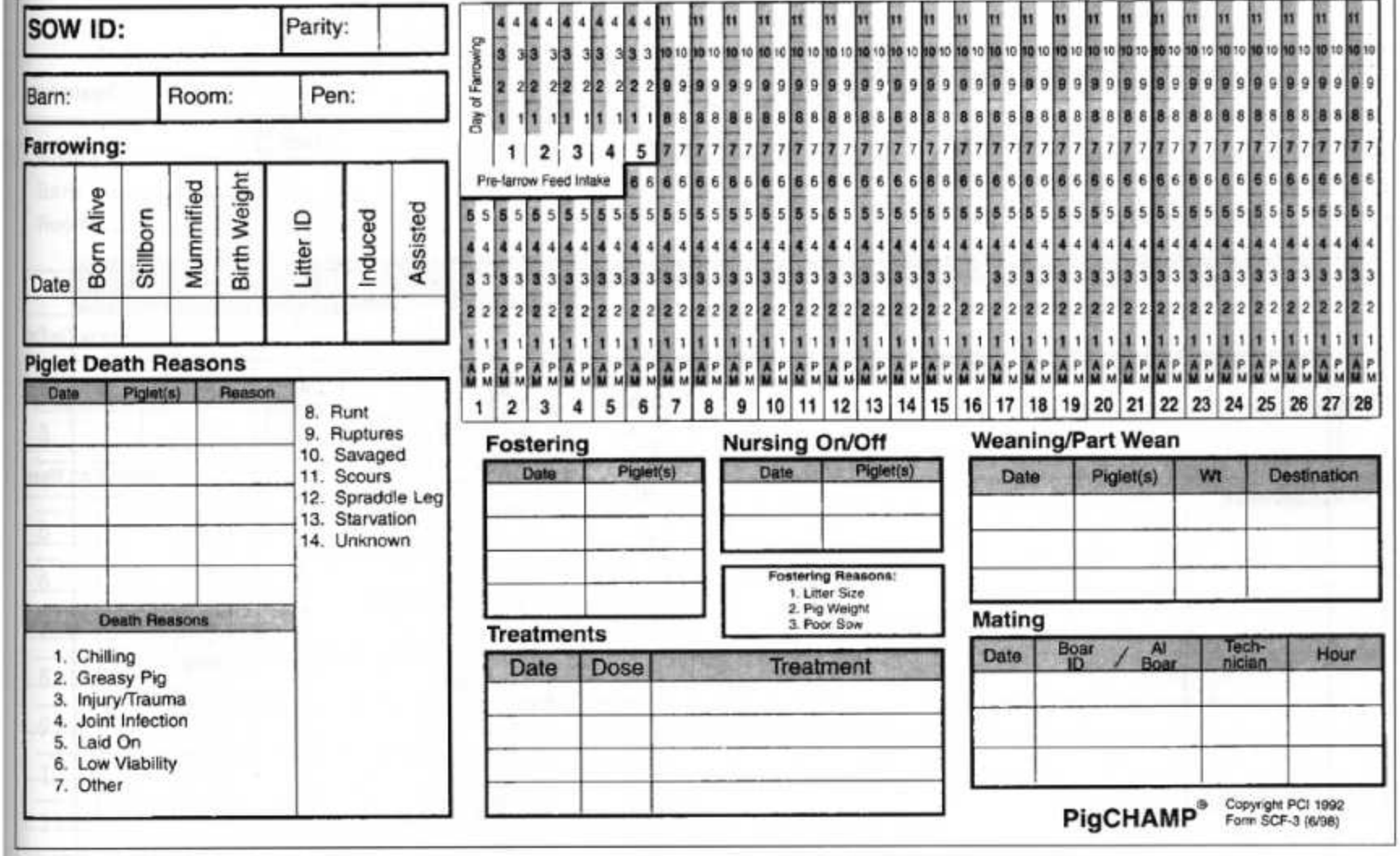

FIG. 15-3 Sow card with data recording area. (Courtesy University of Minnesota PigCHAMP Program, St Paul, Minn.)

herd, and key factors such as farrowing index and feed conversion ratio are calculated on a 6-month rolling average. Individual herd performance may be compared with that of several hundred other participating herds. Record systems that use the Internet are just becoming available.

Output Data. Data are transferred from each site to a central server where reports are run and sent back electronically. Such systems reduce the time lag between data collection and reporting. The possible outputs for a breeding herd are shown in Box 15-2.

Other computer-based systems are available that will monitor the physical and financial performance of the breeding unit, feeding unit, or both. Financial results are reported for each unit and can be given per pig and per sow if requested.

Computer-based recording systems that are oriented toward health and production are available. The computer's store of records consists of a status file and a history file; an archive file is updated each week, and the status file is used for a series of printouts, some of which are produced weekly, whereas others are provided only on demand. These include a weekly inventory of breeding stock; a record of services showing the boar number, sow number, and number of days since weaning; and a list of sows with regular and irregular returns to estrus and sows resulting from farrow.

The history file contains a record of each sow and boar in the herd. The file is used to compute herd productivity data when required. The archive file records sows and boars that have been culled.

A program to monitor reproductive efficiency and weaned pig production using only one data recording sheet is available. Reports will include the following:

- *Production data:* litters produced, numbers born and weaned, mortality rates, and live weight gain of piglets
- *Production efficiency:* pigs weaned per sow in the herd and feed used per weaned pig and per kilogram of weaned pig produced
- *Reproductive efficiency:* analysis of weaning-to-service intervals, farrowing intervals, returns to service, farrowing rates, and boar data comprising numbers born and farrowing rates
- *Records of the lifetime performance of sows and culling rates*
- *Finishing data:* analysis of the live weight gain and grading of bacon pigs

The computer-based program should provide the following:

- *A period report:* this is the most commonly used format and is returned to the producer at the end of each reporting period
- *Performance graph:* simple graphs of several parameters are plotted, using the values for the last six to twelve reporting periods

Computer-based recording systems are an aid to the veterinarian and the swine producer. When each printout is made available, both parties must take the time to analyze and interpret the results of the computer analysis, identify problem areas, investigate those areas clinically, take corrective action, and observe the results.

Text continued on p. 668

A

Treatments

Date			
Treat-ment			
Dose			

Nurse On/Off

Date		
Pigs (+/-)		

Flag	DATE	COMMENT

Notes/Comments:

Farrow

Date	
BA	
SB	
M	
Wt.	
ID	
I	
A	
Barn	
Room	
Pen	

PigCHAMP Knowledge Software

Foster

Date			
Pigs (+/-)			
Rea-son			

Pig Deaths

Date				
No. Pigs				
Rea-son				

Wean/Part Wean

Date		
No. Pigs		
Total Wt.		
Group		
Barn		
Room		
Pen		

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B

FLAG: enter a date and a comment to be recorded under the GENERAL event.

FARROW:

BA -number of piglets born alive
SB -number of stillborn piglets
M -number of mummified piglets
Wt. -total birth weight of pigs born alive
ID -litter ID
I -induced farrowing? (Y/N)
A -assisted farrowing? (Y/N)
BARN -barn ID
ROOM -room ID
CRATE -crate ID

FOSTER:

Pigs -number of pigs fostered on (+) or off (-)
Reason -reason for the fostering

FOSTER REASONS
1. Litter Size
2. Pig Weight
3. Poor Sow

PIGLET DEATHS:

No. Piglets -number of pig deaths with same reason
Reason -reason for deaths

WEAN/PART WEAN:

No. Pigs -number of piglets weaned
Total Wt.-total weight of piglets weaned
Group -group for weaning destination prompt
Barn -barn for weaning destination prompt
Room -room for weaning destination prompt
Pen -pen for weaning destination prompt

TkEATMENTS: to record treatments for sow and litter

Treatment -name of the treatment
Dose -amount of treatment

NURSE ON/OFF:

ON -enter (+) and number of piglets nursed on
OFF -enter (-) and number of piglets nursed off

PIGLET DEATH REASONS
1. Chilling
2. Greasy Pig
3. Injury/Trauma
4. Joint Infection
5. Laid On
6. Low Viability
7. Other
8. Runt
9. Ruptures
10. Savaged
11. Scours
12. Spraddle Leg
13. Starvation
14. Unknown

FIG. 15-4 **A,** Sow card with blank notes area. **B,** Reverse side. (Courtesy University of Minnesota PigCHAMP Program, St Paul, Minn.)

PigCHAMP®

BREED / GESTATION RECORD

Farm _____
Barn _____
Room _____

Period _____ to _____
Page _____ of _____
Week/Group _____

	ID	Alt. ID	Date	Event	Data 1	2	3	4	5
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									

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Commonly Used Sow/Boar Events ABortion Preg Exam To Be culled Mating Remove Not In Pig Skip Heat

More events and data fields are listed on the back.

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FIG. 15-5 A, Breed/gestation record. (Courtesy University of Minnesota PigCHAMP Program, St Paul, Minn.)

Event Reference List

The following is an alphabetical list of the events used to record information and individual sow/boar records. The letters capitalized in the event names represent the abbreviations that are required to enter the events in **PigCHAMP**. Following the event names are the data fields for each event. **(R)** denotes a required field, and **(O)** denotes an optional field.

Event	Data Fields
ABortion	
AI	Boar ID (O) • Technician (O) • Hour (O)
Boars In	Boar ID (O) • Technician (O) • Hour (O)
Boars Out	
Condition	Score (O) • Weight (O) • Backfat (O)
Disease	Disease (R)
Enter	Sex (R) • Parity (R) • Alt ID (O) • Origin (O) • Birthdate (O)
	Genetics (O)
GEneral	Type (R) • Comment (R)
GRoup	Group ID (O)
Heat NS	
LOcation	Barn (O) • Room(O) • Pen (O)
Lost Tag	
Mating	Boar Id (O) • Observer (O) • Hour (O)
Not In Pig	
Preg. Exam	Result (R)
Removal	Removal Type (O) • Primary Reason (O) • Secondary Reason (O)
	Removal Id (R)
Skipheat	
To Be Culled	Reason (O)
Treatments	Treatment (O) • Cost (O)

Data Collection Example

	ID	Date	Event	Date				
1	Y125	1/15/92	PD	2	#4			

On Jan. 15, there were 2 Pig Deaths from scours (reason #4) in Y125's litter.

DEATH • REMOVAL REASONS

Removal Types
1. Cull
2. Death
3. Destroyed
4. Transfer

Death Removal Reasons

Auditory / Visual
1. Auditory / Visual
2. Conjunctinitis / Eye Infection
3. Head Tilt / Eye Infection

Cardio-Vascular
4. Acute Heart Failure
5. Cardio-Vascular
6. Hemmorhaging
7. Pericarditis
8. Vegetative Endocarditis

Central Nervous
9. Central Nervous
10. Meningitis

Gastro-Intestinal
11. Constipation
12. Diarrhea, Acute
13. Diarrhea, Chronic
14. E. Coli
15. Edema Disease
16. Gastro-Intestinal
17. Hemmorhagic Bowel
18. Parasites, Internal
19. Peritonitis
20. Proliferative Enteritis
21. Rectal Prolapse
22. Rectal Stricture
23. Salmonella
24. Swine Dysentery
25. TGE
26. Twisted Gut
27. Ulcer

Urogenital
28. Coryne Suis
29. Leptospirosis
30. Metritis
31. Parvovirus
32. Urinary Infection
33. Urogenital
34. Uterine Prolapse
35. Vaginal Prolapse
36. Vulvar Discharge

Management
37. Behavior Problem
38. Depopulation
39. Genetics
40. Management
41. Market Conditions or Taxes
42. Old Age / Parity
43. Progeny Performance
44. Size
45. Test and Remove

Metabolic Disease
46. Metabolic Disease
47. Stress Syndrome

Multiple Systems
48. African Swine Fever
49. Brucellosis
50. Erysipelas
51. Foot and Mouth
52. Haemophilus Parasuis
53. Hog Cholera
54. Multiple Systems
55. Mycoplasma Hyorhinis
56. Polyserositis
57. Pseudorabies
58. Strep Suis
59. Septicemia Internal Abscess

Musculo-Skeletal
60. Downer
61. Injury
62. Joint Infection
63. Lameness
64. Musculo-Skeletal
65. Osteochondrosis
66. Unsoundness

DEATH • REMOVAL REASONS (cont.)

Body Condition
67. Body Condition
68. Unthrifty

Nutritional
69. Nutritional
70. Parakeratosis / Zinc Deficiency
71. Salt Poisoning - Water Deprivation
72. Toxicity, Mycotoxins
73. Toxicity, Other
74. Vitamin E - Selenium Deficiency

Other
75. Accident
76. Electrocution
77. Hernia / Rupture
78. Off Feed
79. Other
80. Puffer Sow
81. Suffocation
82. Tail Biting

Fertility, Sow
83. Aborted
84. Did Not Conceive
85. Fail to Farrow
86. Fertility, Sow
87. Found Not Pregnant
88. No Heat
89. Pregnancy Check Negative

Respiratory
90. Actinobacillus Suis
91. Atrophic Rhinitis
92. Haemophilus PP
93. Influenza
94. Mycoplasma Hyopneumoniae
95. Pasteurella
96. Pleuritis
97. Pneumonia, Acute
98. Pneumonia, Chronic
99. Respiratory

Skin-Cuntaneous
100. Abscess
102. Cannibalism
103. Chronic Mange
104. Cuts / Lacerations
105. Greasy Pig
106. Skin Infection
107. Skin Ulcers
108. Skin Cuntaneous

Farrowing Productivity
109. Abnormal Pigs
110. Dead or Mummified Litter
111. Difficult Farrowing
112. Farrowing Productivity
113. Hysteria / Savaging
114. Retained Pigs
115. Small Litter Size
116. Small / Weak Pigs

Lactation -Weaning Productivity
117. Agalacitia
118. Disease in Litter
119. Lactation - Weaning Productivity
120. Mastitis, Acute
121. Mastitis, Chronic
122. Udder Trauma

Fertility, Boar
123. Boar Libido
124. Boar Fertility

FIG. 15-5, cont'd **B,** Reverse side of breed/gestation record.

Farm _____

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FARROWING RECORD

Period _____ to _____
Page _____ of _____
Week/Group _____

	Sow ID	Alt. ID	Farrow Date	Born Alive	Stillborn	Mummified	Litter Wt.	Litter ID	Induced	Assisted	Location			Comments
											Barn	Room	Pen / Crate	
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														
14														
15														
16														
17														
18														
19														
20														
21														
22														
23														
24														
25														

Note: If **Sow ID** listed is Alt. ID, place a ✓ in **Alt. ID** column

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FIG. 15-6 Farrowing record. (Courtesy University of Minnesota PigCHAMP Program, St Paul, Minn.)

Farm _____

PigCHAMP Knowledge Software

FARROW / WEAN RECORD

Period _____ to _____

Page _____ of _____

	Sow ID	Farrow Date	Born Alive	Stillborn	Mummified	Litter Wt.	Litter ID	Assisted	Induced	Location			Foster		Foster Reason	Nurse		Part Wean			Wean			Wean Destination			Group ID
										Barn	Room	Pen/ Crate	Date	# On/Off		Date	# On/Off	Date	Piglets	Wt.	Date	Piglets	Wt.	Barn	Room	Pen	
1																											
2																											
3																											
4																											
5																											
6																											
7																											
8																											
9																											
10																											
11																											
12																											
13																											
14																											
15																											
16																											
17																											
18																											
19																											
20																											

Foster Reasons (1) Litter Size (2) Pig Wt. (3) Poor Sow

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FIG. 15-7 Farrow/wean record. (Courtesy University of Minnesota PigCHAMP Program, St Paul, Minn.)

Farm _____

PigCHAMP® Knowledge Software

BREEDING RECORD

Period _____ to _____
Page _____ of _____
Week/Group _____

	Sow ID	1st Mating			Observer	Hour	Comments	2nd Mating			Observer	Hour	Comments	3rd Mating			Observer	Hour	Comments
		Date	AI ✓	Boar ID				Date	AI ✓	Boar ID				Date	AI ✓	Boar ID			
1																			
2																			
3																			
4																			
5																			
6																			
7																			
8																			
9																			
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17																			
18																			
19																			
20																			
21																			
22																			
23																			
24																			
25																			

Note **If mating is AI then place a ✓ mark in front of the boar ID.**

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FIG. 15-8 Breeding record. (Courtesy University of Minnesota PigCHAMP Program, St Paul, Minn.)

BOX 15-2

Possible Outputs for a Breeding Herd

Average number of sows and gilts in herd
Average number of unserved gilts
Average number of sows and gilts per boar
Average number of litters per sow and gilt
Average number of pigs born per litter
Average number of pigs born alive per litter
Average number of pigs reared per sow and gilt
Average number of pigs reared per litter
Average weight of pigs reared (kg)
Feed per pig reared (kg)
Total feed cost per pigs reared
Total feed consumption per kilogram pig produced
Total feed cost per kilogram pig produced
Quantity of sow feed per sow and gilt
Cost of sow feed per sow and gilt
Quantity of pig feed per pig reared
Cost of pig feed per pig reared
Cost per hundredweight of feed

Problems are identified by comparing actual production with targets and then finding significant deviations. Monitoring answers the questions, "What is happening now, and how does actual production compare with the targets?" Production analysis is the investigative or diagnostic stage of the process of monitoring production. Its purpose is to answer the question, "What are the possible causes of the identified problem?" Production reference values provide the standards of health by which the performance of the breeding herd is assessed. Production reference values are averages and SDs for production values achieved by a large group of similar herds.

Production targets are the short-term future goals for a given production unit. They are typically set annually in a 1-year action plan and ought to be based on long-term trends and the actual performance in the previous year. These targets must be biologically feasible, economically realistic, and possible in that particular herd. Targets answer the question, "What do you want to achieve in the next year?" An action plan is a treatment plan based on the results of the analysis and target setting. An action plan lists a set of specific recommendations that, when implemented, should lead to the herd meeting its 1-year production and productivity targets. Action plans may include the use of vaccines, antimicrobials, or other health products; remodeling buildings or making other changes to an environment; redesigning a job description; making personnel changes; restructuring the organization; introducing new genetic lines; and reformulating diets or making other feeding system changes (Stein, 1988).

One difficulty that veterinarians commonly encounter is knowing when to intervene. That is, as performance continues, there will be random fluctuations from week to week. Two types of errors are well described in statistics. It may have appeared that there was a "real" change when in fact there was not, or it may have been assumed there were no changes when there really were. The dilemma is that one never really knows which of these errors is being committed. But it is certain that they occur daily in herd management.

Statistical Process Control. Statistical process control (SPC) is a technique being implemented on many farms to help determine when to intervene. Different farms focus their attention on different production parameters. The following guidelines have been suggested as parameters to monitor (Montgomery, 1996):

- Start by applying control charts to any part of the product characteristic or production process believed to be important (Fig. 15-9). Over time, remove those charts that are unnecessary and add any considered necessary.
- Apply the charts as early in each stage of the production process as possible.
- Implement and maintain the charts as close to the applicable area as possible so that feedback is rapid. Ultimately the data should be collected and charts maintained and interpreted by the staff in charge of that facet of production.
- Anything monitored over time can be analyzed by SPC to interpret the data. This includes measures of production, health, and financial performance.

Possible health and production measures include the following:

- *Breeding herd*: conception rate, farrowing rate, litter size, preweaning mortality, cull rate, and mortality rate
- *Growing herd*: feed and water use, medication use, mortality, gain, fed efficiency, carcass trim, and condemnations
- *Health*: in addition to morbidity indicators and mortality, the prevalence of specific diseases through serology, slaughter checks, and antibiotic resistance can be monitored

Besides the effort and time required to chart every measure, there is good reason to monitor the optimum, not the maximum, number of parameters. This is because some of the time, unusually high or low values will occur and yet nothing has happened in the herd to cause this value. For example, preweaning mortality may be unusually low one week, which may be attributed to an improvement in management. However, it is possible that a relatively low percentage of weeks may have extraordinarily high or low preweaning mortality by chance alone. Interpreting such a signal as a real change would be an incorrect interpretation. Therefore the more measures that are monitored with SPC, the more signals can be expected to be both real and false. Unfortunately, it is not known which signals correctly indicate a change in the herd and which are false. With standard SPC charting, a false signal may be expected approximately every 370 data points. If 100 measures are being tracked at a farm every week, a false signal may be expected every 3 to 4 weeks. But if service is being provided to 50 herds, approximately 15 false signals may occur per week. Each signal requires investigation because it is difficult to know whether it is an indication of a real problem deserving attention or a false signal. The need to attach a cost to each investigation and the cost of monitoring too many parameters become apparent.

The only management step that can be taken to avoid false signals is to minimize the number of parameters to those that are essential. The measures tracked will vary among herds and systems. As described previously in the charting guidelines, the exact parameters and chart techniques will evolve to identify the best method for that farm. The process is charted so that the veterinarian can help the managers do their job.

Interpretation of Animal Health and Production Data

The collection and analysis of health and production data is of little value unless they are used to improve or maintain the efficiency and profitability of the swine enterprise. Whether the data are analyzed manually or with the use of a computer, the actual performance of the herd must be examined and interpreted.

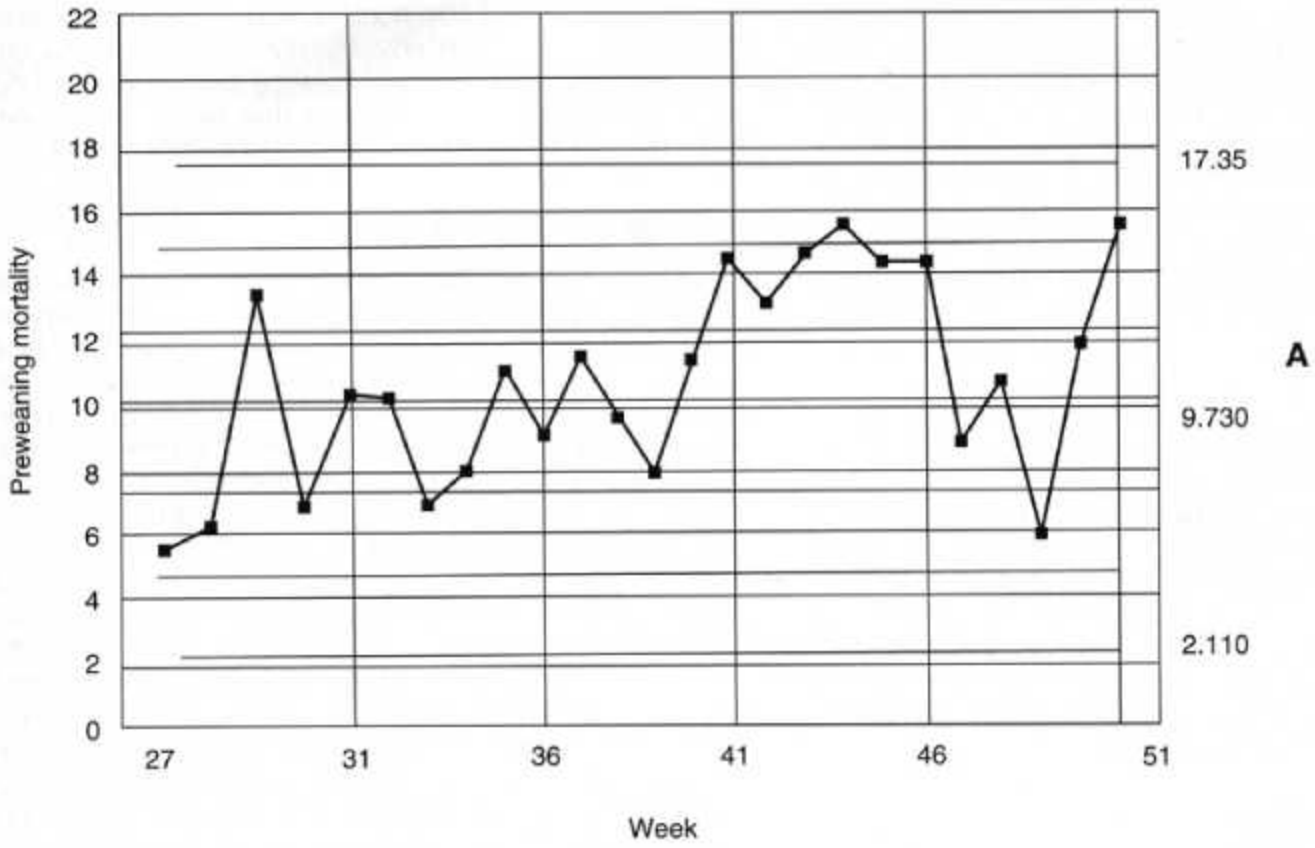


FIG. 15-9 Control chart for preweaning mortality for, **A,** farm 1 and, **B,** farm 2.

The efficiency of the swine unit depends on maintaining a constant flow of pigs through the buildings to make the most effective use of the available labor and facilities, which represents a considerable financial investment. One of the first tasks in planning production that can be achieved with the fixed resources of a swine unit is to set production targets. Subsequently, monitoring of the herd's actual performance reveals whether these initial targets are capable of being achieved. If they are not, they can be adjusted to more realistic levels, but the shortfalls may be due to disease or other problems interfering with the production cycle, and these have to be investigated and corrected. This process of setting targets, monitoring and assessing performance, investigating shortfalls, and revising targets is a continuous one and is dependent on comprehensive and accurate production records.

The best use of resources is achieved by aiming at a level output of pigs throughout the year. This usually means a weekly system of farrowing, with the size of the group being appropriate to the size of the herd that can be sustained. It is important to decide on the size of the herd in the early stages of planning; thus the number of reproductive cycles

can be predicted, and the amount of accommodation for various phases of production can be calculated.

During the first 12 months after the establishment of a swine herd health program, the targets of performance should be assessed at frequent intervals. The critical indexes are the number of services and the number of farrowings per week. These indexes provide a rough analysis of the production process and do not allow an investigation of the cause of shortfalls. A more comprehensive list of indexes must be examined in detail to determine where losses are occurring.

Disease Recording

The records already described are only demographic (e.g., vital statistics). They do not, except by reference, describe clinical disease. The recording of specific disease incidents has not been a major feature of swine herd recording systems. Often, a specific diagnosis of a sick pig is not made by the animal attendant, and the veterinarian is usually not called to examine and treat individual pigs. However, a daily diary should be kept of sick pigs and their location, the treatment given, the number of pigs that died with and without treatment, and the results of necropsies.

Health Status of the Herd

It is often desirable that some overall record of the health status of the herd be available. This can be of value in selling breeding stock and for admission to livestock shows and sales. It is also a guide to whether or not veterinary advisers are succeeding. The report should consist of a list of production indexes for the last 6 to 12 months and the status of the herd with regard to the common infectious diseases, such as atrophic rhinitis (AR), enzootic pneumonia, TGE, swine dysentery, parvovirus infections, sarcoptic mange, and erysipelas. The results of the examination of heads and lungs of pigs sent to slaughter within the last 12 months may also be included. The methods used to determine the disease status of the herd must accompany the report and be certified by the veterinarian. The report should also include a summary of the clinical observations made by the veterinarian over a period of 12 months.

COMPONENTS OF A PLANNED ANIMAL HEALTH AND PRODUCTION PROGRAM

The success of a swine herd health and production program depends on the enthusiasm and competency of the veterinarian and the willingness of the producer to maintain a high level of production through compliance with the consultant's advice as well as good management. This section will describe in general terms some of the methods commonly used to improve and maintain a high level of production and disease control in the swine herd.

Regular Farm Visits

The veterinarian must make regularly scheduled visits to the herd. The frequency of the visits and the length of time actually spent on the farm depend on the size of the herd and the current health and production status of the herd. In the initial stages of a program, the veterinarian may visit the herd once weekly for a few months to gain experience with the herd, to identify obvious problems, and to establish a recording system. Once the program is established, one visit per month to a 100-sow farrow-to-finish operation is often adequate. For larger operations, more frequent visits may be desirable. Telephone consultations, emergency visits, and necropsy services may be provided between the regular farm visits.

The objective of the regular visit is to strive continually for increased productivity by managerial, environmental, and therapeutic control of disease in order to obtain maximum physiological function in that herd. A procedure for routine visits to a swine herd is shown in Box 15-3.

Emergency Farm Visits

Outbreaks of infectious disease that may occur sporadically should be investigated by the veterinarian. Prescriptions for mass medication of the feed or water supplies may be necessary, and it may be legally necessary to examine the pigs. Producers should be encouraged to notify the veterinarian of an unusually high incidence of mortality and of conditions such as dystocia, coughing, and agalactia—all of which should be investigated immediately rather than waiting until the next monthly visit.

A descriptive study of the farm visits made by animal health specialists to growing and finishing pig farms in the Netherlands found that the majority (82%) of visits were made to investigate the cause of health, welfare, and performance problems (problem-solving visits) (Enting et al, 1998). Respiratory diseases were the most common reason for requesting the farm visit. In 18% of the visits the specialists screened for herd-health management factors that did not meet standards for the control of disease. For both types of visits, the common factors detected were abrupt changes in feed composition or feed suppliers, inadequate measures to prevent introduction of pathogens by people or vehicles, and incorrect adjustment of the ventilation system. The diversity of risk factors identified stresses the importance of an overall investigation of farm factors that deviate from the desired standards and the need for an integrated approach.

Nutritional Advice

Veterinarians involved in health management of swine herds must be well informed about the nutrient requirements of the different age groups of pigs. Since feed constitutes 60% to 80% of the cost of producing a market pig, every effort must be made to increase the economic efficiency of feed use. Some surveys of well-managed swine farms in Alberta, Canada, found a 20% difference in feed costs, and it is estimated that in the industry the range in feed costs is likely to be near 50% (Patience and de Lange, 1996). Reduction of the feed cost of the highest costing farm to that of the lowest costing farm would save that farm more than $23,000 annually, which is equivalent to a cost reduction in production of $6.80/pig. The trend is to use complete feeds formulated by feed company nutritionists who are familiar with the nutrient composition of local feedstuffs. With complete diets, specific nutrient deficiencies are uncommon.

The major problem is the efficiency of utilization of the different feeds throughout the life cycle of the pig. The nutrient requirements of the pig at various phases of growth from birth to market weight and of breeding stock are well established. The remaining questions appear to be about the levels of feed that should be provided during the different phases of the growth of the pig in order to achieve optimum production and to yield the best carcass. Proper nutrition can greatly increase the efficiency of swine production, because feed represents such a large percentage of the cost involved. The following are some recommended practices for increasing efficiency of feed utilization with swine:

- Provide well-balanced diets with adequate levels of amino acids, energy, vitamins, and minerals necessary to meet the particular demands of the pig at each stage of its life cycle. The diet depends on the demands, usually characterized as the growth rate or lean deposition. Feed intake

BOX 15-3

Procedure for Routine Visit to Swine Herd

PREVISIT PREPARATION

An appointment is made with the producer at least 1 week in advance; it is important to be punctual at the scheduled time. The following are reviewed and prepared for discussion with the producer:

- Interpretation of previous production reports
- Laboratory results
- Ongoing investigations
- Special topic preparation

CLINICAL AND ENVIRONMENTAL EXAMINATION

Examination of summaries of production indexes and disease incidence since the last visit in order is conducted to identify problem areas:

- Visual examination of each unit of the herd
- Clinical examination of selected sick pigs
- Necropsy examination when appropriate
- Collection of laboratory samples as necessary
- Review of housing, ventilation, sanitation, hygiene, stocking density, and comfort of animals
- Review of feeds and feeding systems

A series of checklists may be used to examine all aspects of each area of the herd. The clinical inspection is made with the herdsperson, and each item in the checklist defines a possible problem and serves as a prompter for the herdsperson to indicate the presence of a problem.

Reproduction and Service Area

Boar/sow ratio
Boar fertility, service problems
Boar usage
Boar condition (e.g., presence of mange, lameness, and other problems)
Weaning-to-service intervals
Return rate and interval of returns to estrus
Farrowing rate
Sow stocking density
Sow body condition (e.g., presence of trauma, stress, lameness, and other problems)
Housing, environment, and temperature
Nutritional levels
Estrus abnormalities
Uterine discharges
Treatments and hormones
Pregnancy diagnosis

Dry Sow Area

Environment and temperature
Stocking densities and stall and tether problems
Feed levels and dung state
Body condition score
Udder line and chronic mastitis
Lameness
Estrus abnormalities
Vulvar discharges
Abortions
Sows not pregnant
Culls and reasons
Sudden death and results of necropsies
Parasite control
Treatments used and reasons

Farrowing and Nursery Area

Sow body condition score
Sows not pregnant
Mastitis, metritis, and agalactia
Farrowing fever
Parturition difficulties
Sudden deaths and results of necropsies
Litter size and scatter
Stillbirths and mummifications
Piglet viability, splay-leg, and congenital defects
Neonatal diarrhea, starvation, and trauma
Mortality levels
Piglet comfort (e.g., use of a heat lamp)
Respiratory disease in nursing piglets (e.g., sneezing, ocular and nasal discharge, nasal deformity, coughing)
Sudden deaths
Diseases of the skin
Parasite control
Treatments used and reasons

Growing and Finishing Area

Age at weaning, body weight, and variability in weight
Nutrition and water availability
Evenness of growth
Postweaning diarrhea
Housing, environment, and stocking densities
Temperature, air quality, and ventilation
Rhinitis and pneumonia
Skin conditions and mange
Vaccination programs
Sudden deaths and results of necropsies
Culls and lameness
Tail biting and ear chewing
Swine dysentery
Days to slaughter
Feed conversion rates
Other diseases
Parasite control
Treatments used and reasons

ANALYSIS AND DISCUSSION OF THE RESULTS OF THE VISIT

Records of performance
Evaluation of diseases encountered
Epidemiological discussions (e.g., what environmental, nutritional, managerial, or other factors are contributing to disease)
Remedial actions and recommendations

Continued

BOX 15-3 —cont'd

Procedure for Routine Visit to Swine Herd—cont'd

SPECIAL TOPICS
Each month a selected special topic may be investigated:
Herd security
Stock introduction, herd replacement policies, and gilt selection
Economic losses in the herd and feed costs and utilization
External and internal parasite control, vermin control, and vaccination program
Fertility and boar management
Herd security check and diseases of the farrowing sow
Piglet problems
Diseases, mortality, and management of the weaned and finishing pigs
Housing use, alterations, and associated diseases
Labor management and productivity
Slaughterhouse monitoring and pathological tests
Twelve-month appraisal and analysis

GENERAL PROBLEMS
Such as flow of pigs through the entire enterprise

PREPARATION FOR NEXT VISIT
Arrange date and special problems to be investigated
Arrange for possible consultation with other specialists (e.g., geneticist, nutritionist, agricultural engineer)

PREPARATION OF THE REPORT
The report is usually prepared in the veterinarian's office and sent to the producer within 2 days after the farm visit

is the supply function. Feed intake is limited by appetite, and thus other nutrients are matched to expected energy intake and subsequent growth.

- Use least-cost formulation to the extent that it is feasible. The least-cost energy source in most of the pig-rearing areas is corn, and the most common protein source is soybean meal.
- Restrict the level of a properly balanced diet for sows during gestation to avoid overfeeding. Sows that have lost excessive body weight in the previous lactation need supplemental feed during the dry period to avoid the thin-sow syndrome.
- Ad-lib feeding for growing pigs is usually optimum unless the genotype deposits excess fat during the latter stages of growth.
- Market pigs as close to optimum slaughter weight as possible to maximize margin over feed costs.
- Avoid feed wastage by using well-designed feeding systems and proper adjustment of those feeders.
- Use pelleting of diets to increase digestibility, especially of small grains, and to decrease feed wastage. However, pelleting also predisposes pigs to gastroesophageal ulcers.

The feed efficiency of the pigs from weaning to market should be monitored regularly. It is often difficult to obtain accurate data on this item for specific groups of pigs, because the amount fed to each group may not be calculable when a common feeding system is in use. However, the total amount of feed used and the total weight of pigs marketed will give an estimate of feed efficiency.

The National Research Council (NRC) in the United States provides an important service in establishing the nutrient requirements of swine and other species. The tenth revised edition of the *Nutrient requirements of swine* was published in 1998 (National Research Council, 1998). The 200-page edition incorporates the wealth of new research information that has emerged over the past 10 years since the eighth edition and addresses new areas such as modelling nutrient requirements and reducing nutrient excretion (Cromwell, 1999).

Even though the nutrient requirements of swine are well known, they do continue to change because of changes in growth and production characteristics of pigs. Pigs with high lean-growth rates require higher levels of amino acids to support their increased rate of body protein deposition. Similarly, high milk-producing sows nursing large litters have increased amino acid requirements.

In the tenth edition, a new approach is used to produce estimates of nutrient requirements that take into consideration not only the pig's body weight, but also its accretion rate of lean (protein) tissue, gender, health status, and various environmental factors. To accurately estimate nutrient needs of gestating and lactating sows, there is a need to account for body weight, weight gain during gestation, weight loss during lactation, number of pigs in the litter, weight gain of the litter (a reflection of milk yield), and certain environmental factors (Cromwell, 1999).

A series of integrated mathematical equations was used to account for the many factors now known to influence nutrient requirements. These equations provide the framework for modelling the biological basis of predicting requirements. The NRC models predict the levels of nutrients (outputs) needed to achieve a certain level of production under a given set of environmental conditions (inputs).

Five principles were used to develop the models. The models: (1) were made for ease of use by people with varying levels of nutritional expertise and with limited information, (2) were developed for continued relevance for several years to come, (3) were intended to be structurally simple, so they could be understood readily by users, (4) were developed to be transparent so that all of the equations could be available to the user, and (5) were firmly anchored to empirical data at the whole-animal level rather than being simply based on theoretical values. Three independent models were developed for growth, gestation, and lactation. The growth model estimates amino acid requirements of pigs from weaning to market weight, and the gestation and lactation models estimate energy and amino acid requirements of gestating and lactating sows.

Few revisions were made in the previously published mineral requirements. Based on recent findings, higher dietary requirements for sodium and chloride in the young pig were established. The manganese requirements were increased from 10 to 20 ppm for gestating and lactating sows.

TABLE 15-9

Heritability Estimates for Traits in Swine

	Percent Heritability
REPRODUCTIVE TRAITS	
No. of pigs farrowed	0-15
No. of pigs weaned	5-15
Fertility	0-15
Age at puberty	0-15
Libido	0-15
PERFORMANCE TRAITS	
Growth rate	25-45
Feed efficiency	25-35
Milking ability	20-30
CARCASS TRAITS	
Length	40-60
Backfat depth	40-60
Longissimus dorsi area	40-60
Thickness of belly	40-60
Percent muscle	40-60
Muscle quality	30-40
OTHER TRAITS	
Disposition	30-50
Udder quality	40-50
Skeletal shape	40-60

Several changes were made in the feed composition tables. Nutrient composition of feeds was obtained from as many data bases as possible, including from the feed industry and from data sets outside the United States and Canada.

The information on water was expanded considerably with more detailed information on the factors that influence water intake. There is additional new information on nonnutritive feed additives, such as antimicrobial agents, anthelmintics, microbial supplements, oligosaccharides, enzymes, acidifiers, flavors, odor control agents, antioxidant pellet binders, flow agents, high-mineral supplements, and carcass modifiers.

A new chapter on minimizing nutrient excretion is included in the tenth edition. It addresses environmental issues and the importance of reducing the excretion of nutrients, particularly nitrogen and phosphorus, which can potentially contribute to environmental pollution.

Pig Genetics and the Selection and Acquisition of Breeding Stock

Veterinarians have traditionally not provided advice on genetics and breeding programs in swine herds. However, veterinarians who become involved in providing a complete swine herd health and production program should be aware of the components of a breeding program: the basic concepts of swine genetics, the heritability estimates of the economically important performance and carcass traits, the importance of records in selection, the performance testing procedures, the value of crossbreeding, and the problems associated with the acquisition of breeding stock that are free of infectious agents.

Basic Concepts of Swine Genetics

Most traits of economic importance in swine may be classified as quantitative traits, that is, traits that exhibit some measurable or observable quantity such as litter weight, growth rate, or backfat thickness. It is true that many qualitative traits such as coat color do exist, but the economic significance of these traits is usually much less than that for the quantitative traits. The exception may be some detrimental recessive traits such as lethal genes or blood disorders that cause either prenatal or postnatal death. These genetic defects should be selected against by choosing breeding stock that are free from defects and whose relatives and ancestors were as free from defects as possible. Basically, qualitative traits are influenced or determined by only one or a very small number of pairs of genes, and the environment plays little or no role in determining phenotype. On the other hand, quantitative traits are influenced by many, perhaps thousands, of pairs of genes, and the environment may play a major role in determining the phenotypic (e.g., performance) value for these traits. The majority of the genes that influence quantitative traits act in an additive manner to influence phenotype. Consequently, selection to improve quantitative traits is aimed at selecting breeding stock with the greatest additive value for a given trait. The fact that the environment also influences phenotype prevents the producer from always being certain that the pig with the highest phenotypic value also has the highest sum of additive genes for the respective trait.

The concept of heritability confronts the problem of separating the influence of genes from the influence of environment upon phenotype. Heritability may be defined as the degree to which relatives are more alike than are nonrelated individuals. Heritability may also be defined as the percent of phenotypic variability among a population of animals that is due to the variability in additive gene action among the members of the population. In simpler terms, heritability refers to the proportion of variability for a trait in a population that is due to additive genes. The remainder of the variability is the result of environmental influences and other types of gene action or interactions. Heritability estimates for several economically important traits in swine are presented in Table 15-9.

It should be clear that, through selection, genetic progress will be more rapid for more highly heritable traits. By simply selecting the boars and gilts with the most desirable phenotypic values, and by using production records and following the practice of mating the best boars to the best sows, the producer should be able to make rather rapid changes for the more highly heritable traits. Both generation interval and intensity of selection play a role in the rate of genetic progress. However, evidence in Canada suggests that selection has been neither intense nor cohesive among breeders, and selection limits are unlikely to be evident for several more decades.

Traits that relate to linear measurements, shape, or composition of pigs are generally high in heritability, and therefore genetic progress can be quite rapid for these traits within purebred swine herds. It is for this reason that breeders have been successful in reducing the fat composition and in increasing the lean or muscle tissue in pork carcasses. Rate and efficiency of gain are also improved through selection, but not as rapidly as traits relating to composition. The best method for improving feed efficiency is to select for increasing the rate of lean growth. This may be accomplished by selecting to increase the rate of growth and decrease backfat thickness.

It is unfortunate that the most important traits from an economic standpoint (e.g., fertility, prolificacy, liveability, libido, and longevity) are quite low in heritability. In fact,

almost all traits that relate to physical fitness or environmental adaptability are low in heritability. This does not mean that purebred breeders should ignore these factors, but rather that genetic progress is generally slow in improving these traits by selective mating.

Genetics of the Pig. An recent book titled *The genetics of the pig* (Rothschild and Ruvinsky, 1998) is excellent. The book provides a complete, comprehensive, and updated description of the modern genetics of the pig. The various chapters by specialists combine the essential knowledge from the various fields of genetics integrated with livestock management in order to provide a useful and informative guide on the genetic improvement of the pig. Recent genetic improvements over the past decade in the pig industry have been dramatic. Tremendous progress has been made in understanding the genetic control of the pig, and considerable success has been made in porcine genome mapping. The book is addressed to a diverse audience including students, researchers, veterinarians, and pig breeders. The initial chapters are devoted to taxonomy and domestication and overview of several pig breeds. There is extensive coverage of the genetics of coat color, morphological characteristics, and inherited disorders. Molecular, biochemical, and immunological genetics are described, and considerable new information is presented. Recent advances in pig gene mapping are included. New areas of developmental and behavioral genetics are explored, as are the genetics of reproduction and new emerging technologies that combine genetics and reproductive biology. The genetics of performance traits and carcass and meat quality traits are included, and there is a section devoted to overall genetic improvement. The major centers of swine breed development were England, China, and the United States (Jones, 1998). The salient features of the common breeds are presented by Porter (1993) and Jones (1998).

Inherited Defects. Inherited disorders of pigs have been of considerable importance, from an agricultural perspective (malignant hyperthermia) and in terms of animal models for inherited human diseases. The literature on inherited disorders has been reviewed (Nicholas, 1998). A total of 161 traits and disorders have been reported in pigs. A complete set of up-to-date references for each entry is available by accessing Online Mendelian Inheritance in Animals (OMIA) on the Internet at http://www.angis.org.au/Databases/BIRX/omia/.

The molecular and gene-mapping revolutions will result in a large amount of information in this area in the years ahead.

Biochemical and Serological Markers. The different porcine biochemical and serological genetic markers and their significance in pig genetics and breeding has been reviewed (Juneja and Vogeli, 1998). One of the main applications of blood markers in pigs has been for parentage testing. Studies of the genetic structure of breeds and populations, estimation of heterozygosity of populations, and estimation of genetic distance between breeds, as well as for linkage studies and gene mapping, have been done. Some studies have led to the detection of the economically important halothane linkage group. The recent finding of linkage between the blood group locus S and the gene determining susceptibility to edema disease may be important in practical pig breeding (Juneja and Vogeli, 1998).

Immunogenetics of Pigs. Information on swine immunogenetics has expanded recently (Lunney and Butler, 1998). Several different approaches have been used to examine the potential for using genetic approaches to improve animal disease resistance. It may be possible to predict the immunological potential of certain populations of pigs that may be more resistant to infectious diseases. These general immune resistance properties could be incorporated into commercial breeding operations. Theoretically, disease-resistant pigs, in well-managed facilities, help decrease the use of antimicrobials in swine herds.

Pig chromosomes are of special interest to farm animal cytogeneticists. The domestic pig (*Sus scrofa*) is cytogenetically the most widely studied farm animal (Chowdhary, 1998). This may be because of the relatively fewer chromosomes in the domestic pig ($2n = 38$) compared with other domesticated farm animals like cattle ($2n = 60$). The pig chromosomes are also readily distinguishable from each other, and it is relatively easy to identify most of the chromosomes even without the use of special staining methods. Techniques used to study the porcine genome have been reviewed (Chowdhary, 1998).

Genetics of Reproduction. The underlying genetic control of reproductive traits and methods of genetic improvement of these traits has been reviewed (Rothschild and Bidanel, 1998). A survey across breeds of swine demonstrates that considerable genetic variation exists for several reproductive measures. Average litter size varies among breeds from 4 to 16 piglets/litter for mature sows. Mean age at puberty varies from 3 to 7 months of age. This, along with genetic variability within breeds, suggests that substantial genetic improvement of reproductive performance in the pig is possible. Genetic differences for reproductive traits exist among and within breeds and lines. Differences among breeds and lines can be exploited most effectively through the use of crossbreeding. Whereas there has been much emphasis on the genetics of reducing backfat thickness, there is now much interest in the genetics of improving sow and boar reproduction (Rothschild and Bidanel, 1998). Experimental results have shown that the least heritable traits such as litter size could be selected successfully in certain circumstances. The use of powerful across-herd genetic evaluation techniques based on Best Linear Unbiased Prediction methodology has provided geneticists with the opportunity to substantially increase the efficiency of selection of these least heritable traits. As a consequence, litter size has become a major component of selection goals in maternal lines of pigs, and annual genetic trends of 0.1 to 0.3 piglet/litter have been obtained recently in some pig populations. Further gains in prolificacy, as well as in sexual maturity and mothering abilities, can be expected in the near future from the increasing use of prolific Chinese breeds or of synthetic lines developed through the use of these prolific breeds in crossbreeding plans. The use of marker genes will also contribute to more efficient use genetic improvement of reproductive traits, which are sex limited and often are expressed later in life.

Breeds of Pigs and Genetic Diversity. Pig production has been increasing in importance in both developing and developed countries. Pig numbers rank second only to poultry in terms of rate of increase: from 1960 to 1990 stocks increased by 45% and 201% in developed and developing countries, respectively. The increase is largely attributed to proliferation of a few breeds of pigs and the erosion of important genetic diversity in several indigenous breeds of pig. At least 20% of all known breeds of pigs are at risk of extinction (Hammond and Leitch, 1998). The greatest cause of genetic erosion is the growing trend to global reliance on one or a few modern breeds suited to high input-output needs of industrial agriculture. This is of major importance because about 50% of the total variation at the quantitative level is between-breed, the remainder being common to all breeds. Therefore a move to one breed would eliminate half this variation in the species, in addition to jeopardizing readily available gene combinations in other remaining unique genetic resources.

Animal genetic diversity allows farmers to select stocks or develop new breeds in response to changes in the environment, threats of disease, new knowledge of human nutrition requirements, changing market conditions, and societal needs, all of which are largely unpredictable. Animal genetic diversity is critical for achieving food security for the rapidly growing population, not only with respect to the local or national situation but also because countries are becoming increasingly interdependent for access to unique animal genetic resources. Furthermore, the lifting of trade barriers should create opportunities for developing countries to achieve more efficient and effective livestock sectors capable of increasing foreign exchange earnings and security for the world's majority. In addition, in developed countries consumer emphasis on product quality is increasing, markets are becoming more segmented, and efficiency of input resource use is being increasingly emphasized. These needs will intensify and should broaden efforts in the genetic development of animals for production, productivity, and product quality and should help sustain primary national and regional agrosystems.

A special action program for the global management of domestic animal genetic resources was begun by the Food and Agricultural Organization in 1992. Details of the program are described (Hammond and Leitch, 1998).

Genetics of Performance. Performance of an animal destined for market in a pork production system is defined by the efficiency with which it develops saleable product. That efficiency is largely determined by the costs associated with feed and time and by the amount of quality lean tissue produced. Genetic merit for market animal performance is improved in seedstock populations by performance testing and selection. For successful pork production, a breeding system must be implemented that optimizes market pig performance and reproductive efficiency. The genetics of performance traits have been reviewed (Clutter and Brascamp, 1998). In a typical selection program, an overall objective is defined and phenotypic measurements are chosen as criteria to estimate genetic merit for the selection objective. For objectives related to performance of the market pig, phenotypic measurements have included postweaning growth (days of age at an ideal market, typically 105 to 110 kg, or rate of gain from around 25 kg to market weight) and live animal backfat thickness at market weight, measured either with a ruler or more recently with an ultrasonic probe. Less frequently, phenotypic records may include individual feed intake and efficiency during the postweaning period and carcass information from relatives. A classical approach to this sort of multitrait selection involves derivation of a linear index of the phenotypic measurements with weightings that maximize its correlation with the selection objective (Clutter and Brascamp, 1998).

Performance and carcass traits in swine are affected by both heredity and environment. Heredity is the sum total of the genes and the combinations of genes that the offspring received from its parents. These are fixed at the moment of conception and cannot be changed thereafter. Environment includes all nonhereditary factors such as feed, management, and disease. The environmental effects can be controlled to a certain extent by the swine producer. Both heredity and environment must be optimum in order to produce swine efficiently. For example, the best feeding and management system possible will provide disappointing results if the animals produced do not have the genetic ability to perform well and to produce superior carcasses. On the other hand, a poor feeding and management system will also give disappointing results even if the swine produced are genetically superior.

The improvement of swine through breeding may be accomplished in two different ways. One way is to find the best animals for important traits when all are compared under similar conditions and then mate the best boars to the best sows. The second way is to cross unrelated strains or breeds to obtain heterosis, or hybrid vigor. The details of the different selection programs for purebred herds and commercial herds using crossbreeding systems are available in standard textbooks on the genetics of livestock improvement (Rothschild and Ruvinsky, 1998).

Breeding Stock Selection

Replacement breeding stock is a major expense in reproduction. It is also a major source of potential in improvement in productivity and quality of output through genetic improvement. It is an almost universal truth in North American production that the genetic improvement is gained through selection occurring off the farm in production systems designed for genetic selection. These systems have had the opportunity to use advanced selection methods and to respond more quickly to consumer demands. Moreover, they have had the scale to provide stock to allow the creation of large sow units.

Paternal genes are purchased as terminal boars or through semen purchases from local boar studs. Maternal lines are likewise often purchased as terminal line gilts. Alternatively, in larger production systems, parent lines are purchased from breeding stock suppliers, and the terminal line stock is produced in-house.

The role of the veterinarian is to aid in the selection of the breeding stock supplier. The criteria for selection of a supplier vary with the farm and the aims of the owners, but they include the following:

- *Familiarity and consistency of the genotype for the output buyers.* For sow units this will involve the buyer's ability to manage that genotype correctly. For meat packers this means that meat and carcass characteristics are expected to be of good quality. Unknown or unfamiliar genotypes are often disadvantaged because they are unknown for buyers and less likely to attain good contracts. Furthermore, inconsistencies with current supplies may be detrimental to processing. Meat-processing companies are starting to own or control the genotypes that enter their plants. One such example is Smithfield Foods, the largest pork producer in North America, which owns its genetic supplier, Northern Pig Development.
- *Freedom from specific pathogens.* The pyramidal and large-scale structure of modern pig production demands that new pathogens be avoided, since the cost is rapidly amplified and eradication is often difficult. This freedom involves current stock and the biosecurity methods to avoid new pathogen introductions.
- *Reliable and good productivity.* Not all productivity indexes can be superlative in the same genotype. Priorities for the farming system must be established. Prolificacy and durability of breeding stock along with feed efficiency; fast growth, and carcass characteristics are often the major characteristics of concern. It is also important to ascertain the priorities of future selection.
- *Long-term viability and improvement of the supplier.* It is costly and risky to change breeding stock suppliers because it allows a greater risk of new pathogens and creates a heterogeneous output.
- *Cost of product.* Costs vary between suppliers and can be a major cost of production. It is important to ensure that these added costs can be recouped through improved productivity or value of the output.

Sources of Breeding Stock

One of the major management decisions of commercial swine producers is selection of the source of breeding stock to be used in the breeding program. A major objective of both the producer and the veterinarian should be to introduce breeding stock with the greatest genetic potential for improving production efficiency. However, a major concern is the introduction of breeding stock that are latent carriers of pathogens able to spread to the home stock. The swine producer has three basic options for introducing breeding stock without introducing pathogens to the herd.

The first alternative is to maintain a closed herd except for the introduction of semen, embryos, or litters taken from their dams by cesarean section. This approach involves the least risk from the standpoint of disease introduction but often results in the lowest level of production efficiency of the three alternatives. The problem with the use of semen on a few selected crossbred sows is that the boars and gilts that will be produced are already crossbred and are probably related to many animals in the herd. There is often a major loss in potential heterosis for herds in which this procedure is attempted. If the commercial producer attempts to maintain a few purebred sows to prevent the loss of hybrid vigor, often the genetic level of these sows will be questionable. If these sows are bred artificially to superior boars, frequently there is little or no selection pressure placed on the progeny.

The second alternative is to purchase all breeding stock from a single supplier. This supplier should meet four basic criteria:

1. The health program of the supplier should satisfy the commercial producer and his veterinarian.
2. The selection and breeding program of the supplier should be planned to make near-maximum genetic progress for the economically important traits.
3. The supplier must have available for sale the breeds or crossbred combinations desired by the commercial producer so that maximum or near-maximum hybrid vigor may be attained by the producer.
4. The supplier must have enough boars available for sale so that the commercial producer may select boars with superior performance records. This approach appears safe from the herd health standpoint. Most of the genetic improvement is left to the supplier, who should be devoting a major portion of his time and resources toward continued genetic progress. Replacement gilts should continue to be selected from the commercial herd.

The third alternative is to use multiple suppliers of breeding stock. These suppliers would likely be two, three, or four purebred breeders of different breeds. If each of the breeders involved has a sound breeding and selection program, then this approach may allow the commercial producer to make optimum genetic progress. There are likely to be more problems with the introduction of disease by using this approach. Many commercial producers have been successful with this program by using careful introductory isolation and testing followed by a planned exposure program.

In Canada the commercial pork industry has shown a marked improvement in average carcass merit in the last few decades. This trend, stimulated and guided by the 1968 revision of carcass grading standards, has been accompanied by a 60% reduction in the number of commercial herds and a threefold increase in the average number of pigs marketed annually per unit. There has been steady growth in the use of systematic crossbreeding programs, and producer demand for boars with performance credentials has greatly intensified. This has fostered an increase in record of performance testing activity, given impetus to the evolution of swine AI programs, and encouraged the development of large closed-herd seed stock operations with self-contained performance test facilities. The central objective of performance testing programs, both private and public, is the genetic improvement of traits directly relevant to efficient lean meat production. Future production requirements are unlikely to alter this basic objective, but advances in the technology for live animal carcass evaluation and changing economic circumstances—specifically, changes in rations to accommodate the increasing competition for cereal grain supplies—will necessitate continuous review and revision of testing procedures.

Efficiency of production varies greatly among production units. It is not uncommon to find the amount of feed required to produce a unit of market weight to be as low as 3.3 to 3.7 for farms with excellent management and as high as 4.5 to 5.0 for farms with somewhat suboptimum management. Differences of this magnitude in production efficiency are not totally due to genetic differences; however, the practitioner should always be aware that performance never exceeds the genetic potential of the breeding stock used in a herd. Therefore the genetic potential should not be the weak link in preventing a production unit from attaining the efficiency of 3.3 units of feed/unit of live hog marketed.

Additional Information on Swine Improvement Programs

Additional information on swine improvement programs and systems is available on the Web through the Canadian Swine Improvement System (http://mark.asci.ncsu.edu/nsif/96proc/cSIS.htm) and the Review of Swine Genetics in the United States (http://mark.asci.ncsu.edu/nsif/95proc/review.htm).

Financial Planning

Swine practitioners are providing financial analysis of swine herd performance on an ongoing basis (Tubbs and Fuchs, 1996). Reasons for financial evaluation include new project proposals, sale of the swine operation, expansion of the herd, depopulation, producers' entering a network arrangement or a contract, intergenerational transfer of the enterprise, and financial difficulties. Three types of financial statements are used to monitor performance: balance sheet, income statement, and cash flow statement. Each of these statements provides information that is essential to the overall financial evaluation. The enterprise budget is another useful tool for analysis of the herd's financial status. It is a statement of planned economic activity for a given period of time. It identifies the likely sources of expected revenues and expected expenses. At the end of the period, the budget is compared with the income statement to determine how closely actual revenues and expenses have matched the projections and to assist in planning the next period's budget. Both the producer and the veterinarian are interested in the costs of production and how to decrease the costs of production and still maintain employee satisfaction, animal welfare, and sufficient profit. The costs of production are feed, labor, facilities and equipment, depreciation and interest costs, maintenance, veterinary services and animal health products, and administrative overhead. As competitiveness continues in the swine industry, the financial evaluation of the swine operation will be an absolute necessity.

Abattoir Surveillance of Market Pigs

Abattoir inspection data have been used in the surveillance of farm animal populations for occurrence of specific diseases as well as for tracing of affected herds as part of national disease control programs. The Danish Swine

Slaughter Inspection Data System provides surveillance of disease among Danish pigs (Willeberg et al, 1984). The system is unique to Scandinavia because the swine producers are strongly organized and supportive of their cooperatively managed slaughterhouses. The bacon industry of Denmark has developed excellent export-based production; maintaining a worldwide market for high-quality Danish pork is a common goal for the government and the swine producers. This has made it possible to introduce a national swine herd health management program to deal with current health problems in the national swine herd.

The keystones of the system are a centralized, computer-based accounting system for cooperative abattoirs and a uniform code list of diagnoses in the meat inspection regulations to specify the lesions causing partial or total condemnation of affected carcasses. Pigs shipped to market are identified by herd of origin through the use of a slap-tattoo. At slaughter, all lesions are examined and diagnosed by licensed qualified veterinarians. The diagnostic data are stored and processed on a central computer, from which data owners receive payment for the pigs with specifications of any deductions for partial or total condemnations. The routine reporting of all slaughter inspection findings for a particular swineherd has been very useful for the individual manager. The information obtained on a national basis is useful in identifying research priorities and providing an extension service to the farmers regarding the prevalent diseases. The data may also be used to conduct epidemiological investigations on farms with a high prevalence of diseases, such as enzootic pneumonia, and compare these farms with those with a lower incidence. A national file of approximately 60,000 herds that deliver pigs for slaughter is updated monthly with current figures for the number of pigs delivered and the number with lesions of the various categories. The updated file is processed to detect those herds for which one or more of the lesion rates exceed critical limits determined by different criteria. A herd file is flagged if the mean rates exceed the critical limits for any of the groups of lesions. The slaughterhouse sends a letter to the producer suggesting a visit to the farm to investigate the problem. If the producer responds favorably, the slaughterhouse arranges for a local practicing veterinarian, selected by the producer and the local extension swine specialist to meet with the producer at the farm. During the investigation and discussion at the farm, a recording form is completed with summary statements about the conditions found and recommendations are made to control the problem. The program currently covers 95% to 97% of all pigs slaughtered within the country. At the chosen level of discrimination, approximately 2.4% of herds are flagged each year and represent 14% to 17% of the pigs killed. There has been general acceptance of the principles and procedures of the scheme. However, producers have had a critical attitude regarding the problem-solving abilities of the veterinarians performing the herd visits.

The validity of the classification of lesions present at slaughter has been questioned. Examination of the data found high degrees of correlation between the occurrence of lesions at routine inspection and the recording of prior clinical episodes and detailed necropsy diagnoses. The meat inspection data have been used in several epidemiological studies, which have provided important information for the development of the national herd health program. For example, the data suggest that frequent problems are not independent, specific diseases but different manifestations of underlying unfavorable environmental and managerial herd factors (Willeberg et al, 1984).

The logistics of examination of swine at slaughter, the epidemiological considerations, and the significance of the findings have been described and are presented in the section dealing with monitoring disease in growing and finishing pigs ("Diseases of Growing and Finishing Pigs") (Straw et al, 1986a,b).

Losses resulting from death of pigs on arrival at the abattoir and condemnation of swine carcasses after slaughter can be substantial. Death of pigs during transport and lairage is a problem in some countries. The causes of rejection of whole carcasses include the pneumonia-pleurisy-peritonitis complex, abscesses, fever, and arthritis. Abscesses are the most common cause of rejection of parts of carcasses. The main reasons for rejection of liver, heart, and lungs were milk-spot, pericarditis, and pneumonia. In a survey of the causes of rejections of pig carcasses in seven abattoirs, which slaughtered 1.3 million pigs, 0.2% of whole carcasses and 2.0% of parts of carcasses were rejected.

Effect of Housing on Performance and Disease Incidence

Complete confinement of the swine herd during production has created many managerial and environmental problems that affect reproductive performance, growth performance, and incidence of disease (Donham, 1998). Inadequate housing and ventilation, poor sanitation and hygiene, and overcrowding are predisposing causes of disease and poor performance. The most economically important health and production problems are multifactorial in origin. The environment in buildings of the intensive pig industry can be associated with health hazards of people employed (Donham, 1998). Veterinarians need a working knowledge of the science of environmental design, control, and monitoring to facilitate their role as swine production and health management specialists (MacDougald, 1988). The various aspects of housing and ventilation must be examined at each visit to the farm. An agricultural engineer who is knowledgeable about housing and ventilation should be consulted when problems are suspected.

A checklist for inspection of such problems would include the following:

1. Sanitation and hygiene, and cleaning and disinfection practices
2. Comfort of animals in their pens
3. Quality of air and adequacy of ventilation
4. Stocking density and overcrowding
5. Quality of floor material and evidence of traumatic injuries resulting from floor surfaces
6. Adequacy of temperature in each section of the pig house
7. Manure disposal

Some of the identifiable risk factors that may interact with each other to affect performance and disease include herd size, herd immunity, feeding systems, quality of flooring, pen cleaning systems, manure storage and disposal systems, ventilation systems, lighting, pen design, and abnormal animal behavior. The major problems appear to be stocking rates and pen sizes, quality of floor surfaces, sanitation of pens, ventilation, and offensive odors from manure storage pits.

All-In, All-Out Systems

In large sow herds, a common practice is to divide the farrowing barn into smaller AIAO units for each week's farrowing group. The gestating sow units are usually housed in a central area, often with an estrus detection facility. Gestating sows may be confined and fed in groups or in individual stalls. Confinement in individual stalls allows for controlled individual feeding and more effective control of sow condition. Nursery units are also AIAO units, usually designed to hold one week's output of weaned pigs. If the nursery is

off-site, it may be designed to hold weanings from a number of sow units.

Ventilation and Air Quality

In most areas where pigs are raised in total confinement, a system of climate control with an effective ventilation system is necessary. The provision of an adequate ventilation system optimizes production, minimizes the spread of aerosol infections, and provides a reasonable working environment for employees. Effective ventilation systems for swine barns are notoriously difficult for an agricultural engineer to design and for the producer to operate and maintain. Many systems are incorrectly planned or used and are not maintained properly. High-low thermometers are often the first test to determine if the ventilation system is capable of maintaining the correct temperature. Effective climate control involves maintaining the temperature at a desirable level with the aid of supplemental heat and adequate insulation of walls and ceilings, achieving a relative humidity ranging from 50% to 75%, and providing satisfactory movement of air into and out of the building. There must be continuous removal of inside air and a continuous supply of fresh, outside air. For optimum animal health, supplemental heat may be required to permit continuous ventilation while an ambient temperature is maintained. The cost of energy for supplemental heat for swine barns in cold climates is a major economic consideration. Fully automated environmental control systems using microprocessors for the control of the climatic environment in swine buildings have been widely adopted by producers.

The ventilation needs for confined swine can be calculated from the size of the building, the number and ages of the pigs, the building materials used, and the outside ambient temperature. Standard formulas are available, and the assistance of an agricultural engineer should be sought. Guidelines that veterinary practitioners can use for monitoring and troubleshooting the environment of swine barns, especially for the weaned pig, have been described (MacDougald, 1988).

In weaned pigs the problem may be a lack of uniform growth in the absence of clinical or subclinical disease. Examination of the general environmental components includes checking the thermostats, the exhaust fans, the air inlets, the layout of the pens, and the manure disposal system. The temperatures in the pens can be monitored to determine the degree of fluctuations that occur over a 1- to 2-week period. A variety of thermometers is available for this purpose (MacDougald, 1988). Any air speed or wind chill reduces the effective temperature that a pig feels. Air speed and patterns in swine barns are easily determined by the use of smoke sticks. They indicate the overall air pattern in a room and are excellent aids to understanding the basics of inlets, air speed, and air pattern. Static pressure can be measured by static pressure manometers.

Dust and noxious gases are part of the environment of a confinement building, and although they cannot be eliminated, they can be controlled at a comfortable level with adequate ventilation. In swine confinement buildings, the gases of primary concern are ammonia, hydrogen sulfide, methane, and carbon dioxide. These gases are produced either directly or indirectly by the animals through respiration or from the manure and its decomposition. It is estimated that the gas of primary concern is carbon dioxide, most of which is produced by pig respiration. The anaerobic degradation of the stored manure causes the release of hydrogen sulfide, ammonia, and methane, which have some known physiological effects that can be controlled with adequate ventilation rates. Monitoring of air quality can be accomplished by comparing key production records with industry standards and by measuring and comparing relative humidity, ammonia, and air velocity at the pig and human level. Instrumentation can help to document environmental problems, and the assistance of an experienced agricultural engineer is desirable to interpret the findings. Carbon monoxide has also been documented as a cause of death in fetuses and newborn piglets. It occurs at toxic levels when there is an improperly operating fossil fuel heater in the barn and air exchanges are inadequate. Routine maintenance of all heaters should be encouraged.

The major health problems that have been epidemiologically associated with inadequate ventilation include enzootic pneumonia, AR, actinobacillus pleuropneumonia, tail biting and other behavioral abnormalities, and manure gas poisoning.

Floor Surfaces

The nature of floor surfaces used in swine barns has contributed to a variety of injuries to the feet and skin and possibly to the locomotor system of pigs. The lack of bedding, such as straw, and rough concrete surfaces can cause skin abrasions of the teats and carpal joints of nursing piglets and abrasions and fissures of the soles and hooves of older pigs (Svendsen et al, 1986). A wide variety of concrete floor surface finishes, plastic-coated expanded metal floors, concrete and metal slatted floors, and asphalt-covered surfacing have been used with varying success. Slatted floors reduce labor requirements but may increase claw injuries (Mouttotou et al, 1999).

Performance of growing-finishing pigs in terms of rate of gain and gain per unit of feed consumed generally has been comparable on partially and totally slatted floors. Where sizable differences in performance have occurred, factors other than slatted floors alone are usually involved. Among these factors are environmental temperature, space per pig, number of pigs per pen, management practices, variable spacing between or careless installation of slats, improper ratio of slat width to space width, insecurely fastened slats, and rough surface or jagged edges of slats. Frequently, the effects of these factors are difficult to assess.

Slatted Floors

More than any other factor, the adoption of slatted floors for swine housing has accelerated the trend to total confinement; with the introduction of partially or fully slatted floors, labor requirements were significantly reduced. Manure is generally stored under the slats, though some barns use under-slat scraping or flushing to remove manure daily to storage outside the barn. In flushing systems, effluent taken from the upper surface of the lagoon is recycled to the end of the swine building where it is used to flush new wastes into the lagoon. Noxious gases and odors formed from wastes can be irritating to both the animal and the animal attendants. The most important gases generated in a swine confinement unit are carbon dioxide, ammonia, hydrogen sulfide, and methane; a large group of trace organic compounds, such as amines, mercaptans, and skatoles, are generated as well.

Building Materials

The rapid intensification of the swine industry led to the use of many building materials that were attractive economically but undesirable for optimum swine production. The use of various floor materials and designs preceded research information, and the culling rates of breeding animals have

been high. This has necessitated the remodeling of older facilities and the building of new facilities after careful consideration of animal comfort and economic reality.

Handling Manure

The handling and disposal of swine manure is a major problem in total confinement production of swine. The daily accumulation of manure on solid floors may contribute to the spread of infectious diseases and may chill the pigs when the lying areas are soiled. In addition, it demands mechanical or hand scraping and cleaning. It is laborious and generally undesirable, because the frequency of cleaning that will maintain relatively acceptable sanitary conditions is prohibitive from a labor and cost standpoint where large numbers of animals are confined.

Cleaning and Disinfection of Swine Barns

Experience in swine herds has shown that increased losses and lowered productivity may occur if the rearing accommodations are not satisfactorily cleaned and disinfected between batches of pigs. Cleaning and disinfection routines are designed to remove most of the microbial population from pig pens during washing and cleaning procedures, followed by the destruction of accessible residual infections by chemical disinfectants, heat or steam, or fumigation. Farrowing, nursery, and growing-finishing facilities must be cleaned in conjunction with an AIAO policy. Breeding areas and gestating sow accommodations need only be swept clean unless herd-level disease problems dictate otherwise. The spread of pathogens in the breeding area could be encouraged to ensure that breeding stock develop an immunity to the agents associated with reproductive failure and neonatal diarrhea.

Cleaning and disinfection routines should follow the following pattern:

1. Remove bulk manure, litter, adherent dirt, and dust from floors, walls, and upper reaches, and dismantle equipment.
2. Soak and prewash pens and equipment with a suitable detergent. A high-pressure sprayer is the most effective and most common method used to clean confinement swine barns. The use of hot water will further speed up the cleaning process. Cleaning must remove all visible signs of dirt and feces. Allow drying after washing.
3. Apply the appropriate disinfectant to the floors, walls, equipment, and upper reaches, and allow drying. Disinfectants that are effective in the presence of organic matter are preferred.
4. Leave the pens vacant for 2 to 3 days if possible.

Pathogens persist in residual dust, porous walls, and floors, and thorough cleaning and disinfection routines using the appropriate products are needed to achieve any significant reduction in the number of these pathogens. The choice of building materials and surfaces that are easily cleaned and disinfected are advantageous in that they lower labor costs and improve sanitation (Madec et al, 1999).

Control of Flies in Swine Barns

The most commonly occurring biting flies of swine include the stable fly *(Stomoxys calcitrans)*, various species of horseflies and deerflies, mosquitoes, and biting gnats. The common housefly *(Musca domestica)* is the most prevalent nonbiting fly associated with swine and other livestock housing. Other nonbiting flies most often associated with swine include little houseflies (*Fannia* sp.), various species of blowflies, and moth flies (often known as pit flies).

Control of Biting Flies

Biting flies can be controlled using a program of regular spraying of the animals with insecticides such as synergized pyrethrins and dichlorvos. Fly baits are useful as a supplement to fly sprays. Larvicides applied directly to fly breeding sources are not normally eliminated by regular manure and sanitation management. Stirofos is available in a feed additive formulation as an oral larvicide. Control of mosquitoes depends on management of areas of standing water.

Control of Nonbiting Flies

The control of filth-breeding flies (houseflies, stable flies, little houseflies, dump flies) depends on sanitation. They are among the most difficult livestock pests to control. These flies develop in moist manure and wet, decaying organic matter of all kinds found around swine premises. All manure, spilled feed, wet straw, and decaying plant material should be removed twice a week to break the breeding cycle of flies. The increased resistance of flies to chemical insecticides emphasizes the need to consider alternative means to chemical control. Biological control techniques are being explored. Proper use of screens and fly traps are two methods of mechanical fly control that can be used, primarily in enclosed swine housing. Insecticides should be supplementary to sanitation and management measures aimed at preventing fly breeding. Residual sprays usually are the most effective and economical for controlling potentially heavy populations of adult flies. These sprays are applied when flies first appear in the spring. Generally, sprays continue to kill flies for up to 4 weeks with one treatment. The sprays are applied to fly resting surfaces, such as the framework of swine houses, ceilings, trusses, electric light wires and fixtures, outside walls, fences, and any other areas that attract flies. Space sprays, mists, and fogs with quick knockdown but no residual action are advantageous where immediate reduction of an adult fly population is necessary (Williams, 1992).

Housing the Sow from Weaning to Parturition

There has been almost universal adoption of individual confinement of pregnant sows and pubertal gilts in stalls. A major advantage of individual stalls is the ease with which individual feeding according to the conditions of the sow can be accomplished. This method also facilitates daily observation of individual animals for any early sign of illness (e.g., vaginal discharges, lameness, abortions, diarrhea) and makes treatment easier. Such observations and treatments are difficult in group breeding situations. However, because the pregnant sows are individually housed on concrete with no bedding and cannot huddle, they are particularly vulnerable to low house temperatures. It is therefore important that sows on restricted energy intakes, particularly those with energy reserves depleted by lactation, should be housed in the correct thermal environment. At 12° to 18° C, the animals are in conditions considerably below their lower critical temperature and require additional feed to achieve the projected live weight increase.

Alternative systems are being considered, including tethers, group housing with computer-controlled feeding stations, group systems with trickle feeders, and extensive housing on deep bedding (den Hartog et al, 1993). No one system is immediately better, but there are real differences in labor costs, welfare, health, and costs. Currently, European countries, particularly Great Britain, have eliminated the use of stalls and tethers and now support the outside housing (Hazas et al, 1998).

For small-sized swine producers with limited capital for new facilities, one successful alternative is low-cost housing (Friendship and Kains, 1998). In Ontario the most popular low-cost housing option is the hoop or tarpaulin (tarp) barn. These tarpaulin-covered, steel-arched structures are about one quarter to one third the cost of fully slatted, environmentally controlled finishing barns. In addition, hoop barns can be dismantled and moved or can be used for other farming purposes. Small producers using hoop barns have successfully created batch-farrowing systems that maximize crate use and sow performance. Batch farrowing can be implemented without compromising farm operations and profit.

Housing the Sow During Lactation

Considerable effort has been expended by the swine and building industries to develop the most suitable farrowing crate. The incidence of piglet crushing is still unacceptably high, but crates can be designed so that the sow is made to lower herself to her knees, before flopping over to the fully recumbent position, by narrowing the width between the bottom rails of the crate. Alternatively, hydraulic or adjustable arms restrict the sow's going down but allow the sow to arise easily. However, the most significant improvements in sow productivity have come through better management of farrowing houses rather than through the buildings themselves. More attention is being paid to sanitation, hygiene and efficiency of use of the farrowing crates. This includes leaving the crates vacant for at least a few days between sows and rational cross-fostering of piglets as necessary. The planned induction of parturition of batches of sows using the strategic administration of prostaglandins has also been a major advancement. Care of the sow includes cooling through air movement, and wetting ensures comfort during hot weather and improves feed intake. The ideal floor surface of the farrowing crate for the newborn piglet remains elusive. Many different perforated floor surfaces have been developed that are nonslip and nonabrasive for the piglets and that are also easy to clean after weaning of the piglets.

Housing the Young Pig from Weaning to 20-kg Live Weight

Early weaning at 3 weeks of age or younger has become commonplace. This trend has precipitated a demand for accommodations capable of housing piglets weighing less than 5 kg with no maternal protection, often with low feed intakes, and in groups matched for size rather than litter groups. The lower critical temperature of pigs weaned at 5 kg is about 27° C; consequently, weaner accommodations must be capable of maintaining temperatures of 30° C, especially in the immediate postweaning period when feed intake is low. All accommodations for young pigs require some form of supplementary heating if the required house temperature is to be maintained when the temperature difference between outside and inside is greater than 12° to 15° C. Housing problems that occur in weaner pens include overcrowding, insufficient feeder and water spaces, postweaning check, and the spread of infections.

Housing the Growing Pig from 30-kg Live Weight to Market

Housing for pigs from 30-kg live weight to market weight has not changed significantly compared with that for other classes of pigs. Pens with partially or fully slatted floors with no bedding holding 15 to 25 pigs are common. The urine and feces collect into a pit under the slatted floor and are removed as slurry on a regular basis. Considerable field research is being directed to the handling of the slurry.

Flow of Pigs Through the Unit

The flow of pigs through a farrow-to-finish operation must occur with optimum efficiency. There must be adequate space in each section of the operation, and a continuous breeding cycle must be established so that there is optimum use of space and a steady supply of pigs. The AIAO system should be used to minimize the incidence of infectious disease. In this system each unit of the swine enterprise is fully occupied by pigs for the necessary time, which is then followed by a complete depopulation of the unit, cleaning, disinfection, and a period of vacancy before being occupied by animals again.

Use of Antimicrobials as Growth Promotants and for Control of Infectious Disease

Antimicrobials are used extensively in swine feed as growth promotants and for the control of certain bacterial diseases (Prescott, 1997). Antimicrobials with in-feed, U.S. label indications for growth promotion and improvement of feed efficiency include sulfonamides, bacitracin, carbadox, tylosin, penicillin, lincomycin, tetracyclines, bambermycins, and virginiamycin. They are used to improve rate of gain-and-feed conversion in growing pigs and to control specific infectious diseases such as swine dysentery. Antimicrobials may be used in the rations of pigs from weaning until the end of the growing period. Prophylactic or therapeutic levels of certain antimicrobials are commonly used when outbreaks of disease occur. Examples of these diseases include *M. hyopneumoniae*, ileitis, and *A. pleuropneumoniae*. The use of antimicrobials in the feed of sows has improved reproductive performance in some situations.

The use of antimicrobials in the feed of food animals may result in the selection of antimicrobial-resistant bacteria that may be transferred to humans. Many expert scientific panels have been convened to review the scientific literature to consider the potential public health risks from using antimicrobials in the feed of food animals. These reports have concluded that, in general, antimicrobial use leads to selection for resistant bacteria, and that given certain circumstances, these bacteria may be transferred to humans. Most recent studies claim that there is a relationship between the use of antibiotics in food animals and the emergence of antibiotic-resistant bacteria and their transfer to humans (JETACAR, 1999; ACMSF, 1999). However, the risk of this occurrence has not been characterized and quantified. Nevertheless, there is increasing pressure on livestock producers not to use antimicrobials for growth promotion and for routine disease control, but to use them under the strict supervision of the veterinarian who has examined the animals and the circumstances requiring the use of antibiotics.

The conclusions and recommendations of the Advisory Committee on the Microbiological Safety of Food, "Report on microbial resistance in relation to food safety" (ACMSF, 1999) concluded that the aim must be to reduce the exposure of farm animal antibacterial populations to antibiotics by the following:

- Constraining the use of growth promoters
- Paying much greater attention to the question of resistance in the approval procedures for veterinary medicines and in postmarketing surveillance
- Stimulating the farming industry, its suppliers, and the veterinary profession to develop strategies for reducing the use of antibiotics for both therapy and prophylaxis

and confronting the difficulties caused by the veterinary use of fluoroquinolones
- Introducing tighter controls on medicated animal feedstuffs
- Improving the understanding of resistance in bacteria isolated from food animals and foodstuffs, and of ways in which the food chain contributes to human infections with antibiotic-resistant microorganisms

It is suggested that these strategies would reduce the chances both of acquisition of resistance by bacterial pathogens, and of transmissible resistance by other farm animal microflora. Also, importantly, there needs to be a greater emphasis on animal health management standards across the food-producing animal industry, including closer attention by veterinarians and producers on the threat of antibiotic resistance (ACMSF, 1999).

The U.S. FDA recently commissioned a risk assessment to estimate the risk to public health of antimicrobial use in food-animal production. The U.S. pork industry is emphasizing the need to adhere to science-based decision making. This is in contrast to some other countries where decisions are being made to withdraw antimicrobials without good scientific justification. For example, the Precautionary Principle in Europe is based on the notion that if someone raises a threat of harm, measures need to be taken to address the concern. The burden of proof of safety rests with the proponents of an activity or technology; it assumes a position of no risk. On December 14, 1998 the European Council of Agricultural Ministers voted to withdraw the feed additive use of bacitracin zinc, spiramycin, virginiamycin, and tylosin phosphate (Anonymous, 1998); three countries—Belgium, Portugal, and Spain—abstained. The ban was imposed as a precautionary measure to minimize the risk of development of resistant bacteria and to preserve the efficacy of certain antimicrobials used in human medicine.

As trade barriers fall, there is an increasing need to standardize the use of additives such as antimicrobials. Consequently, pressure to disallow subtherapeutic antimicrobials in Europe creates a need to address the situation in other countries. It remains to be seen if the desire to adhere to science-based decision making will prevail in the United States.

Growth Promotants in Swine Feeds

Growth promotants cause improvements in growth performance over and above many other means by which performance targets are met. Because the greatest expense in pig production is feed, any method by which the efficiency of utilization of feed is increased may be economically desirable. The types of growth promotants used in pig production include antimicrobials; trace elements, such as the organic and inorganic salts of copper; ionophore antibiotics; tiamulin, which is a semisynthetic derivative of an antibiotic; and probiotics.

The advantages and disadvantages of subtherapeutic antimicrobial use continue to be debated in the literature. In a recent review (Prescott, 1997) the advantages for the producer were described as greater uniformity of growth and reduction in morbidity. Average daily gain may increase by 10% to 23% and feed efficiency from 6% to 8%. For the consumer, the advantages are that the pork is produced at a reduced price, potentially contaminated with fewer bacteria and arguably produced with increased welfare for the pig. The disadvantages for the producer are the consumer and political pressures to avoid using growth promoters, the possible suppression of normal flora, and the possible failure of antimicrobial therapy resulting from resistance induced by subtherapeutic use. The disadvantages for the consumer are the possible tissue residues in pork and the possibility of infection with antimicrobial-resistant bacteria that emerged in pigs fed subtherapeutic antimicrobial. A World Health Organization (WHO) fact sheet states, "The widespread use of antimicrobials for disease control and growth promotion in animals has been paralleled by an increase in resistance in those bacteria (such as Salmonella and Campylobacter) that can spread from animals, often through food, to cause infections in humans" (WHO, 1998). There is increasing pressure from government organizations, such as WHO, and a host of citizen groups to eliminate subtherapeutic use of antimicrobials.

The antimicrobials and other growth promotants approved for use in swine feeds varies among countries. Each country publishes a brochure describing those products that are approved for use as growth promotants, their withdrawal periods, and their incompatibilities.

Strategic Medication of Feed and Water

Three major issues have increased the frequency of infectious disease, including (1) mixing of animals with different levels of immunity and microbial status, (2) increase of population size and stocking density, and (3) stressful situations caused by events such as transport and fighting after commingling. Mortality may be the tip of the iceberg in some disease situations, hence the practice of feed or water medication. Disease in these large and dense animal populations can be reduced and even prevented by prophylactic administration of antibiotics. The veterinarian must strive to balance the benefits of antimicrobial use with the risk of resistance and cost of the product. Having recognized a set of circumstances in which antimicrobial use may be beneficial, a decision to treat is made based on the following criteria:
- The cost of the particular disease
- The effect on well-being of the pigs
- What will likely happen if treatment is not provided (self resolving, staying the same, or getting worse)
- The cost of the proposed treatment
- The likelihood of resolving the problem with these changes and treatment

The most commonly used antimicrobials in the United States, listed in order of frequency, are tetracyclines, carbadox, bacitracin, tylosin, apramycin, and lincomycin (Dewey et al, 1999).

The specific treatment program will be based on the following:
- Presumptive diagnosis based on clinical signs and history
- Herd health history and performance records
- Prevalence and incidence of this disease
- Compliance of owner-staff
- Benefit:cost of treatment options
- Laboratory results (serology, postmortems with culture and sensitivity)
- Clinical experience
- Antibiotic options available

Mass medication of the feed and water supplies of feeder pigs is not without problems. In addition to the costs, it is not always possible to medicate feed supplies that are already in place on the farm, and the medication of water supplies is often difficult to perform selectively unless there is a double waterline in each pen, one of which can be turned off. Medication of the entire watering system may not be necessary and is more expensive. The withdrawal period for each feed additive must be followed to avoid drug residues in meat supplies. Tests to detect drug residues in pigs after slaughter are now available and are used for statistically valid random sampling of pork in abattoirs.

The American Association of Swine Veterinarians (AASV, 2000) issued a statement regarding the use of antimicrobials in swine production. It reiterated its commitment to the use of scientific knowledge and skills for the benefit of society (AASP, 2000). Culture and sensitivity results should be used to aid in the selection of antimicrobial. Therapeutic use should be confined to appropriate clinical indications. Therapeutic exposure should be limited to treating only for as long as needed for the desired clinical response and to treating only the ill or at-risk pigs, treating the fewest animals indicated. Judicious use of antimicrobials, when under the direction of a veterinarian, should meet all the requirements of a valid VCPR. Prescriptions, veterinary feed directive, and extra-label use of antimicrobials must meet all the requirements of a valid VCPR. Extra-label therapy must only be used where deemed appropriate and not expressly prohibited (chloramphenicol, clenbuterol, diethylstilbestrol, dimetradazol, ipronidazol, nitroimidazol, furazolidone and nitrofurazone [except for approved topical use], fluroquinolones, and glycopeptides [e.g., vancomycin]). Veterinarians should work with those responsible to use antimicrobials judiciously. Regimens for therapeutic antimicrobial use should be optimized using current pharmacological information and principles. Antimicrobials considered important in treating refractory infections in human or veterinary medicine should be used only after careful review and reasonable justification. Contamination of the environment with antimicrobials should be minimized whenever possible. Accurate records of treatment and outcome should be used to evaluate the therapeutic regimen.

In swine herds of today the veterinarian is responsible for making medical judgments, has sufficient knowledge of the animals to initiate at least a preliminary diagnosis, and is readily available in case of adverse reactions or failure of the treatment regimen. Veterinarians have a unique understanding of the broad array of production systems in which pigs are raised. Antibiotic use is a critical component and must be balanced with the needs of the farmer, the pig, and the public.

PRINCIPLES OF CONTROL OF INFECTIOUS DISEASE IN THE SWINE HERD

The presence of certain specific infectious diseases in a swine herd can have a serious limiting effect on efficient production. Some endemic infectious diseases can cause significant economic losses as a result of high mortality, suboptimum growth rate and feed efficiency, and high drug costs. The objectives of a disease control program are to improve animal performance, such as days-to-market and feed efficiency, to improve net profit, and, if possible, to eliminate the disease from the herd or control its prevalence at a low enough level that it does not significantly limit production economically. Some of the economically important infectious diseases of swine herds include the following:

- Enzootic pneumonia (*Mycoplasma* spp.)
- Porcine reproductive and respiratory syndrome (Lelystad virus)
- Multi-systemic postweaning syndrome *(Circovirus)*
- Pleuropneumonia *(A. pleuropneumoniae)*
- Swine dysentery *(Brachyspira hyodysenteriae)*
- AR (i.e., turbinate atrophy)
- Sarcoptic mange and other ectoparasitisms such as lice infestation
- TGE
- Neonatal piglet diarrhea (Enterotoxigenic *E. coli*)
- Porcine parvovirus (PPV) infections

In addition, certain infectious diseases are considered exotic to some countries whereas they occur sporadically in swine herds in other countries. These include the following:

- Aujeszky's disease (pseudorabies)
- Hog cholera (classical swine fever [CSF])
- Swine vesicular disease (SVD)
- Vesicular exanthema
- FMD

The veterinarian and the swine producer must decide which diseases should be controlled or eradicated in the herd based on the prevalence of the disease, the economic losses caused by the disease, and the probability that the disease can be controlled or eradicated. The diseases of concern vary from herd to herd and from country to country.

Epidemic Diseases of Swine

Several diseases of pigs are known as the important epidemic diseases. They are CSF (hog cholera), African swine fever (ASF), FMD, and SVD. These diseases are on the Office International des Epizooties (OIE) List A, which are defined as "transmissible diseases which have the potential for very serious and rapid spread, irrespective of national borders, which are of serious socioeconomic or public health consequence and which are of major importance in the international trade of animals and animal products" (Pedersen et al, 1996).

Outbreaks of the aforementioned diseases in meat-exporting countries are of major consequence because of export bans. When serious outbreaks of disease occur, the eradication measures required and the export ban have severe economic consequences. Therefore adequate prevention and control programs are of great importance to both government and private industry. The risks and consequences of introducing CSF into the Netherlands by feeding swill (garbage) to swine have been examined using risk simulation models (Horst et al, 1997). An outbreak of CSF in the Netherlands in 1997 caused estimated losses of $400 million (U.S. dollars), excluding losses from market disruptions (Horst et al, 1997). By April 1997, more than 120 farms were affected. High losses are due to government purchase and destruction of pigs from farms located within the protection zones where movement of pigs is prohibited. A decision support system for managing swine fever epidemics using an epidemiological program (EpiMan) has been described (Stark et al, 1998).

All outbreaks of List A diseases are immediately reported to the OIE and, in the European Community, to the European Commission. The outbreaks that occurred over a 10-year period are shown in Table 15-10. These diseases are important not only for the economic losses that occur on affected farms but for the major adverse economic consequences for international trade.

Classical Swine Fever (Hog Cholera)

CSF occurs in Asia, Central and South America, and parts of Europe and Africa. Many countries are now free of the disease. In August 2000 the European Commission banned the export of live pigs and porcine semen from England after the first outbreaks of CSF (hog cholera) since 1986 were confirmed on five farms in East Anglia (Anonymous, 2000). A large number of outbreaks of the disease have been confirmed in Germany, the Netherlands, Spain, and Italy in 1998.

The earliest record of hog cholera in the United States dates to 1883 in Ohio (Jordan, 1998). In the early 1890s, control was achieved using hyperimmune serum from pigs repeatedly vaccinated with the virus. In 1934 a vaccine was developed that provided 90% protection. The first

TABLE 15-10

Outbreaks of Office International des Epizooties List A Diseases in Pigs in the European Union (1982 - 1993)

Year	Classical swine fever	African swine fever	Foot-and-mouth disease (all species)	Swine vesicular disease
1982	300	381	24	28
1983	809	734	177	6
1984	1271	206	80	1
1985	486	441	131	1
1986	185	1065	151	0
1987	145	1442	173	0
1988	32	1334	11	1
1989	83	488	74	0
1990	252	413	0	0
1991	22	289	0	6
1992	39	178	0	38
1993	120	143	57	15

Data from Davies G: *Vet Rec* 135:567-577, 1994.

commercial license for modified live-virus vaccine production was issued by the USDA in 1951. In 1961 legislation was introduced to provide for a national eradication program. The use of vaccines was gradually phased out. The eradication program was designed in four phases: Phase 1, preparation; Phase 2, reduction of incidence; Phase 3, elimination of outbreaks; and Phase 4, protection of reinfection. Many outbreaks occurred during the eradication program because of breakdowns in regulations. Identification of the sources of infection was as important as identification of infected herds. The prime threats to herds were the addition of outside animals and neighborhood animals. Uncooked garbage accounted for some of the outbreaks. In January 1978, the United States was declared "hog-cholera free." The eradication of hog cholera was a major benefit to the swine industry. The key to eradication was a close working relationship with veterinarians and leaders in the industry. The compliance of the livestock producer was also a crucial factor to success. The ability to combat the introduction of foreign animal diseases to the United States was accomplished. Foreign markets were opened for breeding stock. It was truly a success story in animal disease eradication.

The recent outbreaks of CSF in Germany and Belgium illustrate some of the risk factors involved. Both epidemics were due to the movement of infected weaner pigs from a small breeding unit in one area to finishing units elsewhere in the country. The main risk factors are infected wild boars, densely populated pig areas, and long distance transport. The major factor in the resurgence of these diseases in areas previously considered free is the rapid development of the swine industry and the trade in live pigs that supplies it.

African Swine Fever

ASF is a highly contagious disease of domestic swine and European wild boar *(Sus scrofa)* caused by an isohedral, double-stranded DNA virus. The disease was first described in Kenya in 1921 with reported outbreaks of peracute disease accompanied by a high mortality and extensive hemorrhage of tissues; it was subsequently recognized in other countries of Africa, where it continues to be an economically devastating disease. In the late 1950s ASF appeared for the first time outside Africa, in the Iberian Peninsula. Depending on the infecting virus isolate, the clinical disease ranges from peracute to chronic, and recovered pigs may become healthy carriers. Currently there is no vaccine and the only effective control policy is based on identification and slaughter of infected pigs. It was present in four South American and Caribbean countries but has been eradicated.

Foot-and-Mouth Disease

FMD affects all ruminant species and swine. The epidemic in the United Kingdom in 2001 was first recognized in pigs at an abattoir. The pigs originated from a farm that allegedly had been feeding swill (table scraps from restaurants and other eating establishments). The epidemic began February 20, 2001; by May 2001, almost 2 million animals (cattle, sheep, pigs, goats) had been slaughtered and buried or burned as part of the eradication program. It also appeared that the disease had been present in sheep for several weeks before it was recognized in the swine herd. It is endemic in parts of Asia, African, the Middle East, and South America. A porcine strain of FMD may have been responsible for recent outbreaks in the swine population of Japan and Korea. Transmission of these diseases can be by direct contact between animals, from wild boars, and from the ingestion of feed (especially garbage fed to pigs) contaminated with the virus.

Many countries give high priority to preventing the introduction of highly contagious diseases such as CSF and FMD into their animal populations and have eradication policies in place to deal with outbreaks. The European Commission and its member states have directives in place to take action in the event of an outbreak of disease (Davies, 1994). The main provisions of these directives are:

1. If disease is suspected, an official investigation must follow.

2. When the presence of disease is confirmed, all susceptible stock on the holding must be slaughtered, the carcasses destroyed, and the site cleaned and disinfected.
3. A restriction zone of 3-km (protection) and 10-km (surveillance) radius must be established around each outbreak; within these the movement of susceptible animals is prohibited until all the herds have been screened.
4. Vaccine (CSF and FMD) can only be used under exceptional circumstances.

Swine Vesicular Disease

SVD has been recorded in Hong Kong, Japan, and several European countries. It is caused by an *Enterovirus* of the family Picornaviridae. The morbidity may be high, but mortality is low. There is no treatment and no vaccine available.

DISEASE CONTROL STRATEGIES

There is some variation in the terminology used to describe disease control strategies. Prevention, control, and eradication are terms commonly used to describe control strategies (Martin et al, 1987). In practice, the terms are commonly used interchangeably, and more than one strategy may be applied to reduce the prevalence of a particular infectious disease to a low level or to eliminate it from the herd.

Prevention is generally applied to those measures designed to exclude disease from an unaffected population. This applies to measures to exclude pathogens from certain geographic areas by quarantine or to protect a given population in an infected area by vaccination. Swine dysentery, enzootic pneumonia, sarcoptic mange, and AR can be prevented in swine herds through the use of certain strategies.

Control strategies are directed toward reducing the frequency of existing disease to levels that are biologically and economically tolerable or are otherwise of little consequence. The producer and the veterinarian may decide to tolerate presence of the disease because alternative methods of prevention or eradication may not be possible or are too costly. Control implies activities conducted at the population level. Piglet diarrhea caused by enterotoxigenic *E. coli* can be controlled at a low incidence in the herd; there are no techniques available for its eradication.

Eradication strategies are directed at the elimination of certain pathogens from a defined area, which may be at the level of the herd, the state, the country, or the world. In the strict sense of the word, "Eradication is the extinction of the pathogen that causes the infectious disease in question; and so long as a single member of the species (the pathogen) survives, then eradication has not been accomplished" (Done, 1985). For certain diseases, such as hog cholera and FMD, the country may have an eradication policy that includes slaughter and disposal of infected animals. Hog cholera, Aujeszky's disease, and SVD are examples of diseases that can be eradicated from herds and countries. Countries will sometimes introduce country-wide programs to eradicate certain diseases such as Aujeszky's disease. The literature commonly refers to the eradication of specific diseases, such as swine dysentery and sarcoptic mange, from swine herds, but these diseases would not necessarily be eradicated from the geographic area and could be reintroduced into a herd that had at one time eradicated them.

The tradition of farm animal disease control in the Nordic countries compared with the rest of Europe is interesting (Pedersen et al, 1996). All the Nordic countries were free of the OIE List A diseases in 1994. In contrast several of these diseases were present on the mainland of Europe. The explanation for this situation is complex but is probably based on the isolated geographic location, restrictive importation of animals and animal products, education and organization of farmers, and a long-standing tradition of solving animal disease problems by eradication when possible and economical. There is also a strong relationship between the expectations of consumers and those of farmers and veterinarians.

PRRS, TGE, and PRCV infections have never been reported in New Zealand (Motha et al, 1997). Passive surveillance for these diseases, as well as for other OIE List A and B diseases, is done routinely by the Ministry of Agriculture's animal health surveillance program. A serological survey of pig herds in 1996 for PRRS, TGE, and PRCV found no evidence of infections. Pseudorabies was first diagnosed in the North Island of New Zealand in 1976; it had never been reported in the South Island. An industry-funded eradication program was initiated in 1989 to eradicate the disease from the national pig herd. Through the use of a combination of serological surveys, abattoir surveillance, test and slaughter, depopulation, vaccination and movement restrictions, the disease was eradicated by 1997 (Pannett et al, 1999).

Diagnosis of Infectious Disease

Before any of the infectious diseases can be controlled or eradicated, there must be a reliable method of making a definitive etiological diagnosis. When the disease is already present, a diagnosis is necessary so that specific control or eradication procedures can be planned and carried out. A diagnostic test with high sensitivity and specificity is desirable so that the progress and success of the control program can be monitored with a surveillance system that will detect evidence of infection in a population and provide an estimate of its prevalence. Serology is becoming an increasingly important aid to monitor infectious diseases that potentially can enter a herd when new breeding stock is imported. Good serological tests are available for some of the major swine diseases and infections such as PRRS, PR, TGE, PPV, *A. pleuropneumoniae*, leptospirosis, *M. hyopneumoniae*, erysipelothrozoonosis, and swine dysentery. Enzyme immunoassays are being used more commonly for the diagnosis of several infectious diseases of pigs at the herd level. Diagnostic cytology is also used for the diagnosis of coccidiosis, *Clostridium perfringens* enterotoxemia, *E. coli* infection, swine dysentery, bacterial meningitis, and sarcoptic mange (Van Alstine et al, 1987). Another method of monitoring for disease is the examination of lungs and snouts of pigs from a herd at the slaughterhouse or the regular serum-antibody testing for specific pathogens, which is discussed in the section on slaughterhouse examination of lesions ("Diseases of Growing and Finishing Pigs").

Infectious Disease Control Strategies

Control of an infectious disease means reduction of the prevalence to the lowest level possible with the management techniques and economic resources available. One or more of the following strategies can be used.

Test and Removal of Infected Animals

The elimination of infection by test and removal (T&R) of positive animals can reduce the prevalence of infection in the herd. The process of T&R may be an efficacious strategy and is currently under investigation. Test and removal has been used successfully to eliminate Aujeszky's disease virus

and *A. pleuropneumoniae*. In herds infected with PRRSV, the primary focus of this strategy is to test all breeding animals, identify carriers, remove them from the herd, and prevent vertical transmission of PRRSV (Dee et al, 2000). Analysis of sera using ELISA for the detection of antibodies along with PCR for the detection of viral protein are used in combination to identify previously exposed, potentially infected animals. The detection of carriers is critical because of the ability of PRRSV to produce persistent infection.

In the case of a herd infected with PRRSV, the T&R program is recommended when the prevalence of infection in the herd is below 50%. This method requires testing of the entire breeding herd and immediate removal of all seropositive animals; 30 days after removal of seropositive animals, the herd is retested and, if necessary, at 30-day intervals until the entire herd tests are negative. Following a second negative test, the testing regimen may be changed to test only 25% of the herd every 4 months. Seropositive animals are identified and culled. The T&R method is superior to the vaccination system as a method of control. Valuable genetic material may be salvaged from breeding stock that are seropositive by using embryo transfer techniques. Embryos may be transferred safely to susceptible recipient gilts from sows that have recovered from infection, but not from sows that are in the active stages of infection. The virus does not penetrate the outer covering of the embryo, but it can become attached to it so that it may physically transfer to the uterus of the recipent. This transfer of infection may occur if the donor sow is in the active phase of infection.

Reduce the Prevalence of Disease by Early Recognition and Treatment

The common bacterial diseases like pleuropneumonia and swine dysentery are treated with antimicrobials. In many cases the disease affects many pigs over a short period, which necessitates the treatment of individual animals that are clinically affected and the mass medication of the feed, water supplies, or both in an attempt to treat subclinical infections before they cause clinical disease. This strategy will be beneficial in some cases and not in others, depending on the specific disease, adequacy of housing, ventilation, stocking density, and management expertise. In well-managed herds diseases like swine dysentery, pleuropneumonia, and enzootic pneumonia can be handled effectively by using strategic therapy; in poorly managed herds the results may be unsatisfactory. The principle of medicated early weaning is to initially control and then eradicate endemic infections such as *M. hyopneumoniae* and *S. hyodysenteriae* (Alexander, 1988). Reduction of the prevalence of the disease decreases the number of infective animals that can transmit the infection to susceptible animals. The strategic use of anthelmintics in pigs will effectively control internal parasites that cause economic losses as a result of mortality, morbidity, condemnation of organs at slaughter, decreased rates of gain, and suboptimum feed efficiency and carcass quality (Biehl, 1986). The control of the important ectoparasites, such as mange, requires regular administration of insecticides to all animals. As an example, sarcoptic mange is not easily controlled because the mites are hidden in burrows or beneath thick scabs of the skin, which are difficult to reach with an acaricide. Cure and control depends on adequate treatment of every pig, including the sows before farrowing—and, if necessary, retreatment 10 days later—and the weanlings and growing pigs before they enter the finishing pens. The boars must also be treated regularly. In addition, the administration of topical insecticides must be done carefully so that all areas of the skin are covered. A prefarrowing treatment of sows with ivermectin is highly effective in preventing transmission of mange mite to the piglets (Dalton and Ryan, 1988). Unfortunately, the prevalence of some of the commonly occurring diseases such as pleuropneumonia cannot be reduced reliably by treatment of affected pigs, because the infection cannot be totally eliminated from the lungs following treatment; therefore recovered pigs can act as reservoirs of the pathogen, and the disease will remain endemic in the herd. The selection of the most cost-effective antimicrobial and the development of drug-resistant strains can create problems.

Reduce Infection Pressure and Minimize the Opportunities for Transmission of the Infection

The AIAO system of managing a group of pigs at each stage of the production cycle is an effective method for the reduction of infection pressure. Groups of pigs are moved into a section of the barn, managed in that section or in pens as a group, moved to the next section as a group, and marketed as a group. The pens are cleaned and disinfected between groups of pigs. A combination of mass medication of the feed of all pigs in a herd, except the nursing piglets; cleaning and disinfection followed by a period of vacancy for 2 weeks; and placement of sows and their piglets in these newly cleaned pens led to the eradication of swine dysentery without depopulation (Wood and Lysons, 1988). The cleaning, washing, and disinfection of farrowing crates between successive sows is also an effective method of reducing infection pressure on newborn piglets. High population densities promote the rapid spread of infection, with a heavy attack rate of infection from infected to susceptible animals; therefore the crowding of pigs in pens must be avoided. The conventional method of rearing pigs, in which they had access to feces-contaminated surfaces, resulted in a high prevalence of gastrointestinal helminthiasis. Current systems of swine herd management have resulted in a very low prevalence of intestinal parasitism, because piglets do not become infected in early life. They are born in clean farrowing crates from sows that have not had ready access to pig manure or contaminated ground, which are sources of the common swine endoparasites. Feeding and watering systems must minimize fecal contamination. The successful treatment of diseased animals will also contribute to a reduction in infection pressure for noninfected animals.

Identify and Minimize the Risk Factors Associated with Infectious Diseases using Effective Management and Production Methods

Risk factors for infectious diseases are usually associated with the environment, the host, and the pathogens. Some commonly known examples of environmental risk factors include inadequate ventilation and wide temperature fluctuations in certain parts of the swine barn, particularly during very warm and very cold seasons; breakdowns in the ventilation system; and inadequate floor space per pig. Examples of host factors include the failure of newborn piglets to obtain sufficient colostrum from their dams, which is a major contributing factor to neonatal diarrhea, and the weaning of piglets too early (e.g., before 3 weeks of age), which may result in a high incidence of postweaning diarrhea associated with rotavirus and enterotoxigenic *E. coli*. Risk factors associated with pathogens include the ability of some pathogens to remain latent in animals that have recovered from disease or in the environment and thereby provide a source of infection for noninfected animals.

Enhance Herd Immunity from Natural Infection or by Vaccination

Under the extensive system of rearing pigs, herd immunity developed because pigs of all groups and ages, including the boar, mixed on a regular basis, and the common pathogens were spread between pigs. Under intensive conditions—in which the dry sows are kept separate from the lactating sows, the weanlings are kept separate from the growing-finishing pigs, and the boars are kept separately—herd immunity to the common pathogens may not develop to the same extent. In an attempt to stimulate herd immunity under these conditions, the feeding of some feces from the sows in the farrowing house to the sows in late pregnancy (e.g., 2 to 4 weeks before farrowing) has been recommended. However, the effectiveness of this technique has not been validated, and the unhygienic nature of the practice may make it questionable. Mixing newly introduced gilts to dry sows, cull sows, and finishing pigs is also recommended to naturally immunize them against the common pathogens, such as enteropathogenic *E. coli*, PPV, and TGE virus. Some diseases of swine can be controlled or prevented by vaccination. However, for the economically important endemic diseases such as enzootic pneumonia, pleuropneumonia caused by *A. pleuropneumoniae*, swine dysentery, sarcoptic mange, and AR, vaccines are either not available or those that are not efficacious.

Genetic Selection for Natural Disease Resistance

The term natural disease resistance refers to the inherent capacity of an animal to resist disease when exposed to pathogens, without prior exposure or immunization. Animals can defend themselves by at least three host defense mechanisms: the epithelial barrier, nonspecific immunity from cells of the immune system, and specific immunity from recovered natural infections or vaccination. The first defense barrier, the epithelium, provides receptor sites for the attachment of many pathogens. Genetically determined variation in the structure of a cellular receptor would cause some animals to be resistant to colonization by a specific pathogen. The classic example of such genetic variability is the resistance of certain pigs to the K881 strain of *E. coli* because of the absence of an appropriate receptor for attachment of the organism to intestinal epithelium. Swine-breeding programs used to increase the degree of natural resistance of the pigs will not completely prevent infectious diseases. Any form of resistance to any infectious disease is relative rather than absolute. However, the increased degree of natural resistance conferred by selective breeding would reduce morbidity and economic losses caused by infectious diseases. There are no documented practical recommendations available for the control of infectious diseases of pigs by genetic selection.

High-Health-Status Herds

In the early days of breeding-stock supply herds, the control of economically important endemic infectious diseases was attempted using the *specific pathogen free* (SPF) herd concept. Pigs were hysterectomy derived and, after a period of isolation, were placed in a nonsterile environment where they became infected with a range of microflora classed as normal. However, they were not infected with specific pathogens such as those that cause enzootic pneumonia and AR, and they were designated free of these diseases (Muirhead, 1989). Pigs from these herds were designated as SPF pigs.

After some years, the term *minimal disease* (MD) herds emerged and was used interchangeably with SPF, but MD became associated with the belief that the pigs were free of the major infectious diseases, although they were not. Muirhead proposed the use of the term *high-health-status herd*, which is a *"herd of recognized health status through the absence of the major infectious diseases."* The diseases would be defined for each particular herd by the consulting veterinarian. The purpose of the term is to ensure that each herd provides evidence of the continued absence of each disease. It is important to emphasize that the terminology does not describe the animals as being free of any infectious agent, but that the observations and tests indicate the disease to be absent. This is important in legal terms, because it would be impossible to claim freedom from a pathogen; at any point in time, the pig could unknowingly be in a period of incubation. The high-health-status designation allows the precise health profile of the herd to be described by the veterinarian. The interpretation of the health status will vary among herds, but it would be expected that most of the major infectious diseases would not be present. Diseases or infections that are absent in a high-health-status swine herd are listed in Box 15-4.

In some countries, FMD, ASF, swine fever, Aujeszky's disease, tuberculosis, and *B. suis* infection would not normally be present because of current national disease-eradication policies. For example, the swine population in Canada is free of the above diseases. However, enzootic pneumonia, AR, disease caused by *A. pleuropneumoniae*, swine dysentery, TGE, and sarcoptic mange are of major economic importance, and producers and veterinarians aim to eliminate these diseases from their herds.

The recognition of the presence or absence of the aforementioned diseases in a herd of pigs can be difficult, because reliable methods of diagnosis may not be available. A typical example is deciding if a particular herd is free of disease caused by *A. pleuropneumoniae*. Should the required standard be the complete absence of the organism on bacteriological and serological examinations or the identification of a herd with no history of disease on clinical or pathological grounds? (Muirhead, 1989). Pigs from such a herd would be capable of integrating safely into commercial herds without risking the introduction of pathogenic serotypes or disease. The criteria for demonstrating the absence of major infectious diseases in a high-health-status herd depend on the diagnostic tests that are available and

BOX 15-4

Foot-and-mouth disease
African swine fever
Hog cholera (classical swine fever)
Aujeszky's disease
Transmissible gastroenteritis
Porcine reproductive and respiratory syndrome
Swine pox
Epidemic diarrhea
Enzootic pneumonia
Actinobacillus pleuropneumonia
Glasser's disease
Streptococcal meningitis
Atrophic rhinitis
Disease caused by *Brucella suis*
Salmonella choleraesuis
Swine dysentery
Lice
Tuberculosis
Parvovirus

their sensitivity and specificity, the results of pathological examinations, the examination of organs at slaughter, and the herd life history, depending on the particular disease in question.

A high-health-status herd can be established when the herd is first populated using pigs purchased from donor herds that are free of the diseases in question or through depopulation and repopulation of an existing herd. The donor herd must be investigated by the producer and the veterinarian. The investigation should include the herd history; all veterinary reports; the animal health and production records, including growth and feed conversion rates; the results of specific tests performed; and a report written by the veterinarian of the donor herd declaring that certain diseases have not been present in the herd over a specified time.

Maintenance of the high-health-status herd is a challenge. The minimum objective in establishing a high-health-status herd is to maintain status quo for at least 2 years, reduce the days to slaughter by 10 to 21, and improve the feed conversion ratio by 0.1 to 0.4. Ideally, a farrowing rate of 90% should be attainable with a growing mortality of less than 2.5%. Enzootic pneumonia, for example, is one of the most difficult diseases to keep out of a herd that is initially free of the disease. Diseases can enter the herd through the air, the mechanical transfer of infected manure, or a carrier pig. The swine barn should be sited at least 500 m away from other pig farms.

Mechanical transfer of pathogens can occur through birds, dogs, cats, and other forms of wildlife. The feed trucks delivering feed to the farm may be a source of infection, but it is difficult to quantify the risk. The role of man as a mechanical transmitter of pathogens has been controversial. What period of time must elapse before a veterinarian who works in one herd enters another herd? It is recommended that the minimum requirement for a veterinarian or other personnel visiting a high-health-status herd would be no contact with pigs of another herd on the same day. All herds should provide boots and coveralls, and showering should be an option.

Genetic improvement of high-health-status herds can be done by importation of live pigs, AI, or embryo transplant (Muirhead, 1989). The introduced pig is the most common source of new infections in the herd. It can be purchased from an existing herd of known high health status or derived by hysterectomy. A veterinary certificate that states the herd of origin is free of the infection should be obtained. If the herd is free of enzootic pneumonia, incoming animals are placed in isolation for about 8 weeks, and sentinel pigs from the recipient herd should be moved in and slaughtered before the entry of the new breeding stock into the herd proper.

Importation of Breeding Stock into Breeding Units

A major problem in the establishment of new swine breeding units and introduction of replacement animals into existing herds is the source of the breeding stock. Clinically normal gilts and boars may be latent carriers of infectious agents, which may be shed and spread to resident nonimmune animals in the herd, causing an epidemic. This is particularly important in large herds of 250 to 500 sows, in which an epidemic can cause major economic losses. The larger the unit, the greater the investment and the loss if disease occurs. Outbreaks of infectious disease tend to be more serious, persist longer, and are more difficult to control in larger units. Some notable examples of diseases that can be introduced by carrier animals include TGE, enzootic pneumonia, Aujeszky's disease, swine dysentery, leptospirosis, and AR. This creates a conflict between the desire to prevent the introduction of infectious diseases and the need to introduce new genes in order to make genetic progress.

Until about 1960, the purebred breeder was the source of pedigreed gilts and boars. The only assurance that the purchaser had of obtaining breeding stock free of the endemic diseases was the statement made by the vendor that the herd was not recently affected with the diseases. This was not and still is not reliable. There is no totally reliable method for determining that imported breeding stock are not carriers of the diseases previously mentioned.

Government-sponsored, central performance test stations were popular from 1960 to 1975, and they emphasized the identification of select breeding stock by testing animals for highly heritable traits such as growth rate, feed conversion, and carcass quality. Disease control in these centers was less than desirable because test animals came from many sources and were housed together at the stations; following the test the boars would be purchased as breeding stock and be introduced into herds.

The need for high-quality breeding stock free of several common diseases soon became obvious and led to the development of multiple-herd breeding networks known as a breeding pyramid (Hammond and Leitch, 1998). In this network, *nucleus herds* supply breeding stock to *multiplier herds,* which in turn supply breeding stock to *commercial herds.* The nucleus herd is established from hysterectomy-derived piglets raised in isolation and known as SPF or MD pigs. In the simple pyramid system, the nucleus herd is a closed unit, and all replacements are hysterectomy-derived pigs. The health and disease security-system standards must be high. The multiplier herds supply breeding stock to the commercial herds, which in turn produce pigs for slaughter.

Theoretically, a 500-sow nucleus herd can provide replacements for 6000 grandparents in multiplier herds. Multiplier herds can provide replacements for 90,000 parents in commercial herds, which in turn can produce 1.5 million slaughter pigs/year.

Biosecurity and Health Monitoring: Application of the Principles to the Production System

Veterinarians can provide an important service in the swine industry by using a "systems approach" to health maintenance and disease monitoring. The following section sets out the design of a large production system, including the layout of buildings, animal flow, biosecurity protocols, and a disease monitoring and response plan. The intention is to describe the application of the principles outlined in this chapter to a large production system that is representative of the future of the swine industry.

Health Status of Breeding Stock

A critical component of any successful swine production system is the selection of a breeding stock source that has the highest level of health. Ideally, breeding stock should be free of the following pathogens: PRRSV, *M. hyopneumoniae,* pseudorabies virus, TGE virus, *A. pleuropneumoniae,* sarcoptic mange mites, toxigenic *Pasteurella multocida* type D, postweaning multisystemic wasting syndrome (Circovirus), swine influenza virus H1N1/H3N2, *B. hyodysenteriae,* and *S. choleraesuis.*

Veterinary communication and health status documentation must occur before purchase. A monitoring program should be in place within the source herd, and testing should take place weekly by the collection of a representative

sample of each pig population, using both serology and PCR when available. Proper sample sizes should be calculated according to population size, the desired level of confidence of the sampling protocol, and the sensitivity-specificity of each test used, according to published methods. Finally, diagnostic evaluation of tissues collected from clinically abnormal pigs should be carried out as needed.

Farm Size and Animal Flow Calculations

The proposed production model described in this section is provided in Figs. 15-10 and 15-11. The *basic production unit (BPU)* of the system comprises 33,000 sows. Each BPU contains a 130-boar AI center, an internal multiplication unit of 3000 sows, two −3000-sow P1 production-gilt development units, eight −3000-sow commercial units with wean-to-finish pig production facilities, a vehicle processing area, and a veterinary center. The 33,000-sow BPU can then be multiplied as often as necessary to achieve the total desired number of sows within the system, (e.g., 33,000 sow BPU × 6 units results in nearly 200,000 sows.

Replacement Stock Introduction

Grandparent replacements for the system enter the internal replacement unit as weaned piglets and are raised in facilities specifically designed for this purpose (Fig. 15-12, *A*). Based on production parameters of 2.3 litters/sow/year and a 9-pig weaning average/litter, the 3000 sow multiplication unit is capable of producing approximately 600 gilt piglets/week. Three hundred gilts are available for each of the two 3000 sow P1 production farms located within the BPU.

Parity 1 Production Farms

The purpose of each P1 unit is to raise, breed, gestate, and farrow gilts in order to wean P1 adult females into four commercial 3000 sow farms within the BPU. This process allows for the designation of labor and removes the gilt pool from the commercial component of the system. Production of each 3000 sow P1 production operation is based on 2.3 litters/sow/year, which is equivalent to 6900 farrowings/year, or 133 farrowings/week. Since this unit consists of only gilt farrowings, a conservative selection rate and farrowing rate is important to ensure sufficient gilts for mating. The use of a 70% gilt selection rate and a 70% gilt farrowing rate results in a gilt pool inventory of 270 females/week in order to produce approximately 135 weaned P1 sows for introduction into the commercial system.

Commercial Production Segment

Each of the four commercial farms within each BPU consists of 3000 sows. At a 45% annual replacement rate, 1350 P1 sows are required each year (26/week). Therefore, over all four units, 104 P1 sows are required each week, well within the projected weekly production level (n = 135) of the P1 farm. The value of a 3000-sow inventory is the production of approximately 1200 weaner pigs/week, allowing for all-in, all-out pig flow and stage depopulation of each wean-to-finish facility at the end of a 24-week period. This calculation is based on 2.3 litters/sow/year and a nine-pig/litter weaned average.

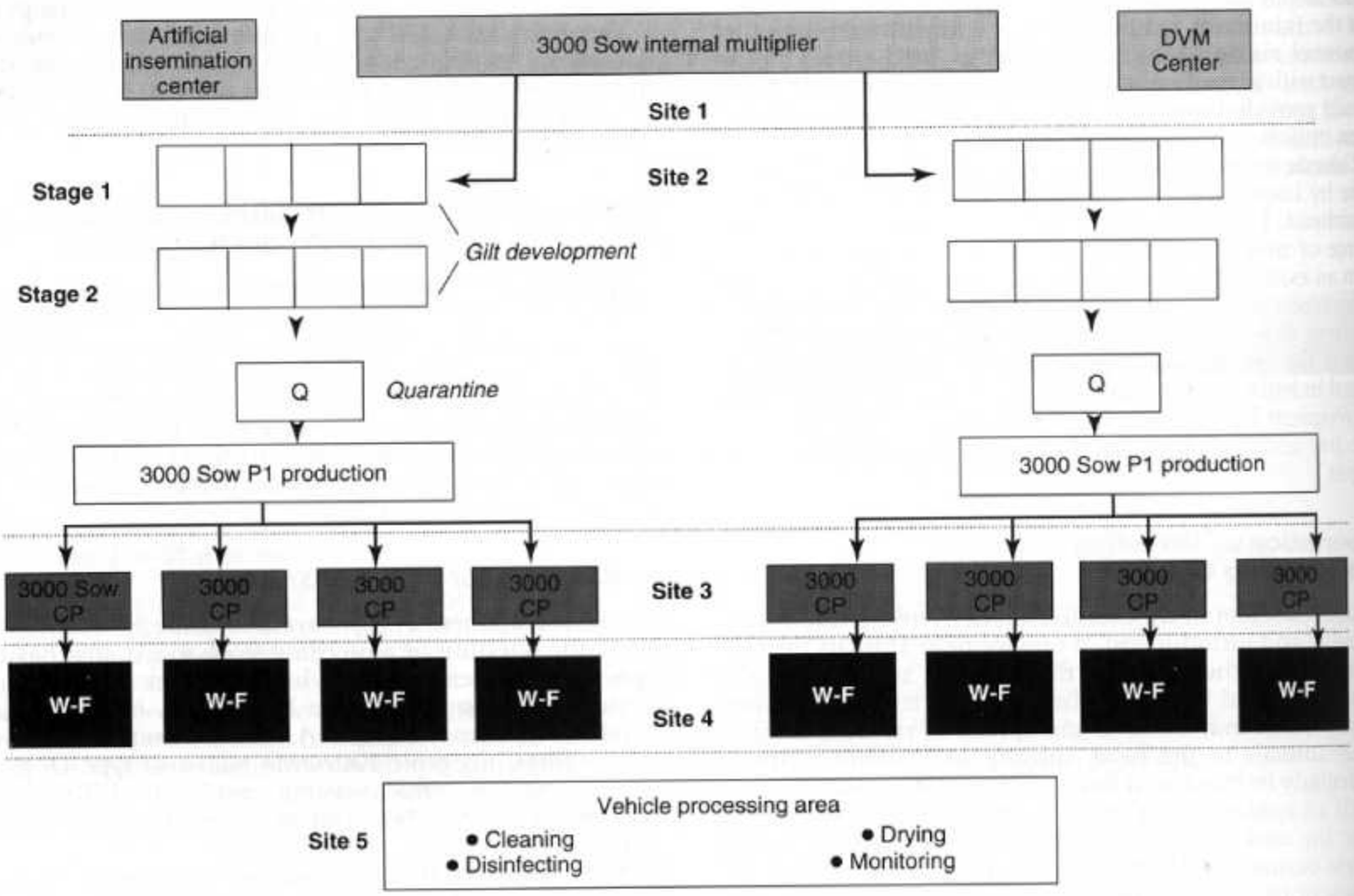


FIG. 15-10 Layout of the basic production unit consisting of 33,000 sows. *CP*, Commercial production; *DVM*, doctor of veterinary medicine; *W-F*, wean-to-finish.

Artificial Insemination Center

In combination with the BPU, an AI center of approximately 130 boars produces the sufficient number of doses of semen for the 33,000 sows at 2.5 doses/service and 2.3 litters/sow/year. Boar inventory is calculated based on an average of 30 doses/boar/week and 1500 doses/boar/year. According to the above calculations the BPU requires 190,000 doses/year; therefore 125 to 130 boars are housed in the AI center. Boars enter a quarantine center 60 days before introduction to the boar stud at a targeted age of 6 months.

Biosecurity Program: Breeding Herd

The facilities and the animal flow program for the quarantine of replacement breeding stock and the weaned P1 sows before entry into the commercial segment are illustrated in Fig. 15-12. Replacement stock initially enter a stage 1 quarantine, consisting of four rooms, each filled on a weekly basis (Fig. 15-12, *A*). A representative sample is collected from each room each week and tested according to the health assurance protocol. Although the entire facility will not operate on an "all-in" basis, it will operate "all-out"; therefore the oldest pigs reside in the facility for 4 weeks and the younger animals for 1 week, for testing purposes only.

Following completion of the 4-week stage 1 quarantine, the entire group moves to a wean-to-finish gilt developer containing four rooms to house four monthly groups. This facility will run all-in, all-out by room, but under a continuous flow airspace. After 16 weeks in this facility, each monthly group passes through a 30-day quarantine testing period before entry into the breeding herd of the internal multiplication unit. These animals complete their first gestation and lactation periods, thereby being classified as P1 sows. The point of health monitoring within this segment of the system occurs 7 days before weaning, before entering the P1 production farm's gilt pool area. A representative sample of P1 sows scheduled to be weaned the following week are tested. After completion of the lactation period, P1 sows are weaned into 1-week quarantines before entering the commercial production operation (Fig. 15-12, *B*).

To further reduce the risk of pathogen entry, breeding is done using AI. The AI center within a BPU is a separate site. Semen is distributed by a courier service to neutral delivery points located at the perimeter of the BPU. Vacuum tubes transport the delivered semen into the breeding area through an underground system. The AI center is monitored weekly through PCR testing of the semen and monthly serological evaluation of boars. Finally, biosecurity is further enhanced through the practice of a minimum of 48 hours free of swine contact and shower facilities for all personnel before their entry into the sow and boar centers.

Biosecurity Programs: Weaning to Finishing

For personnel movement between weaning-to-finishing facilities, the following protocol is in place: four such facilities compose a site, separated by a minimum of 100 m (Fig. 15-11). A "support building" containing a shower area, office, and wash area serves as the entry point for each site. The support building layout is shown in Fig. 15-13. Personnel enter the facility using a door on the contaminated side of the support building. This area also houses the site-specific loading chute for washing, disinfection, and storage. All equipment enters the noncontaminated side of the support building through fumigation rooms, and individuals enter using the shower protocol.

Following completion of the shower-in procedure, personnel put on clothing and footwear for movement to and between wean-to-finish facilities. Upon entry to each wean-to-finish building, a standard program of entry is in place consisting of a change of coveralls and boots, followed by a hand-face wash and use of a footbath before entry into the animal air space. This procedure is repeated between each facility on the site.

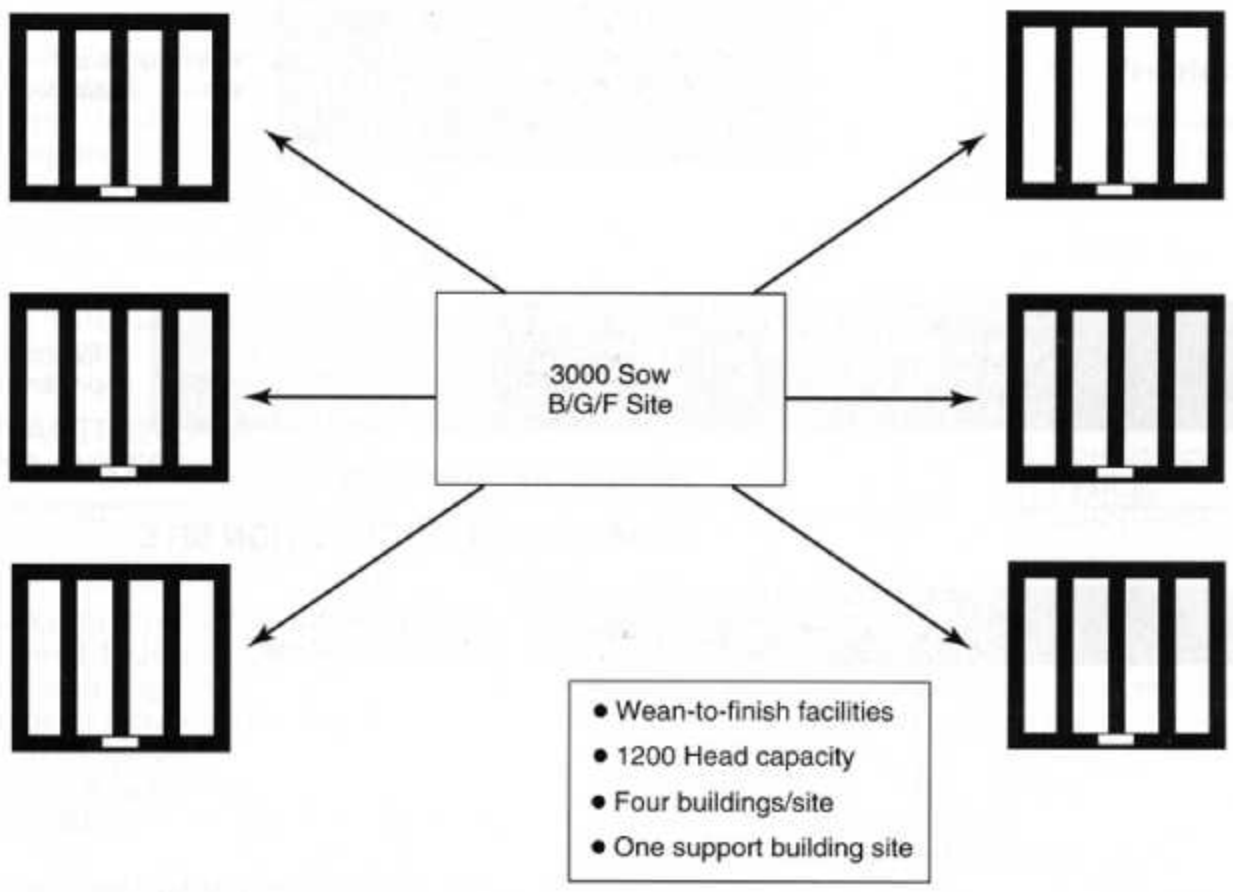
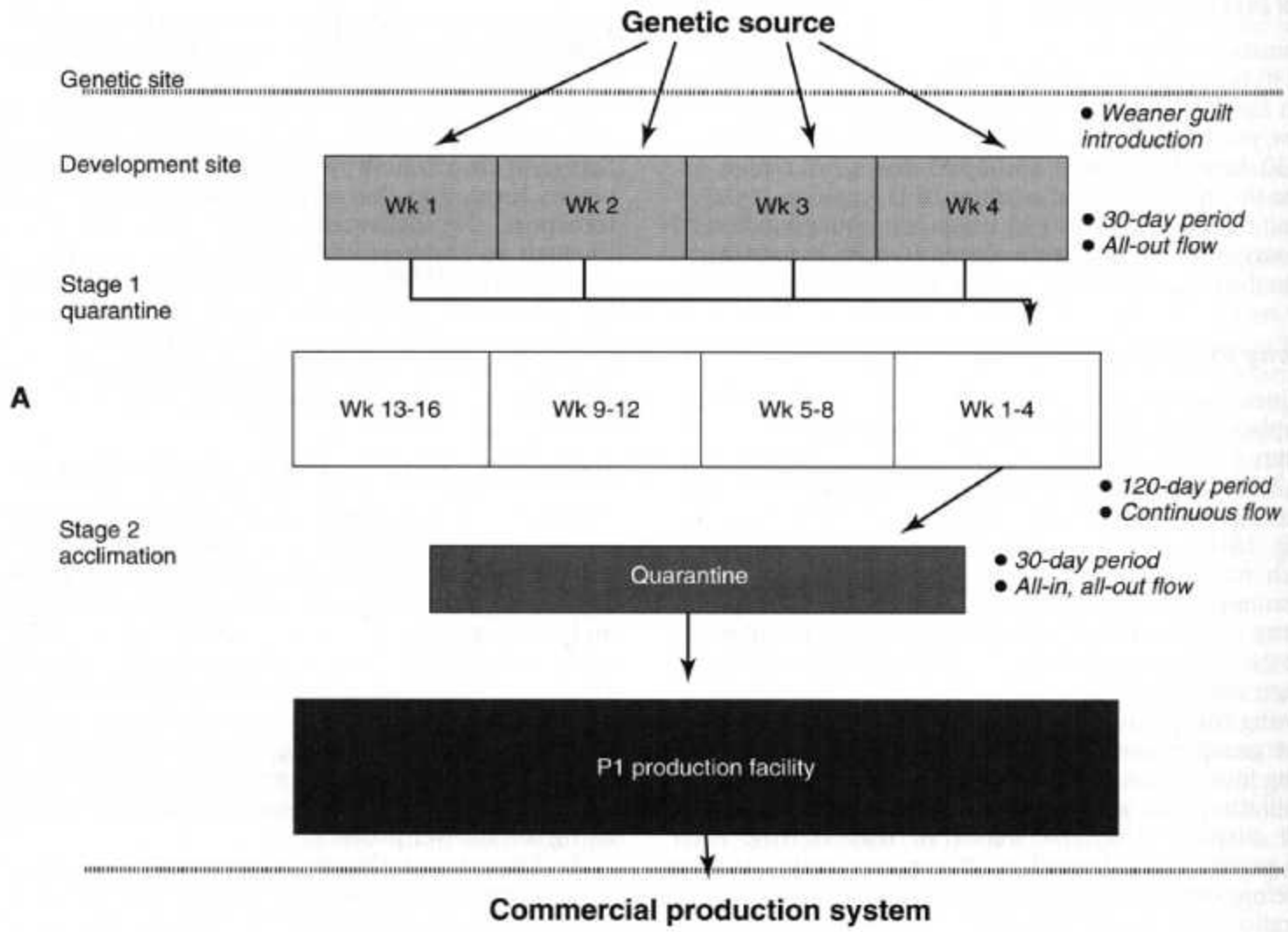


FIG. 15-11 Layout of an individual 3000-sow commercial production unit with wean-to-finish facilities. *B/G/F,* Breeding, gestation, farrowing.



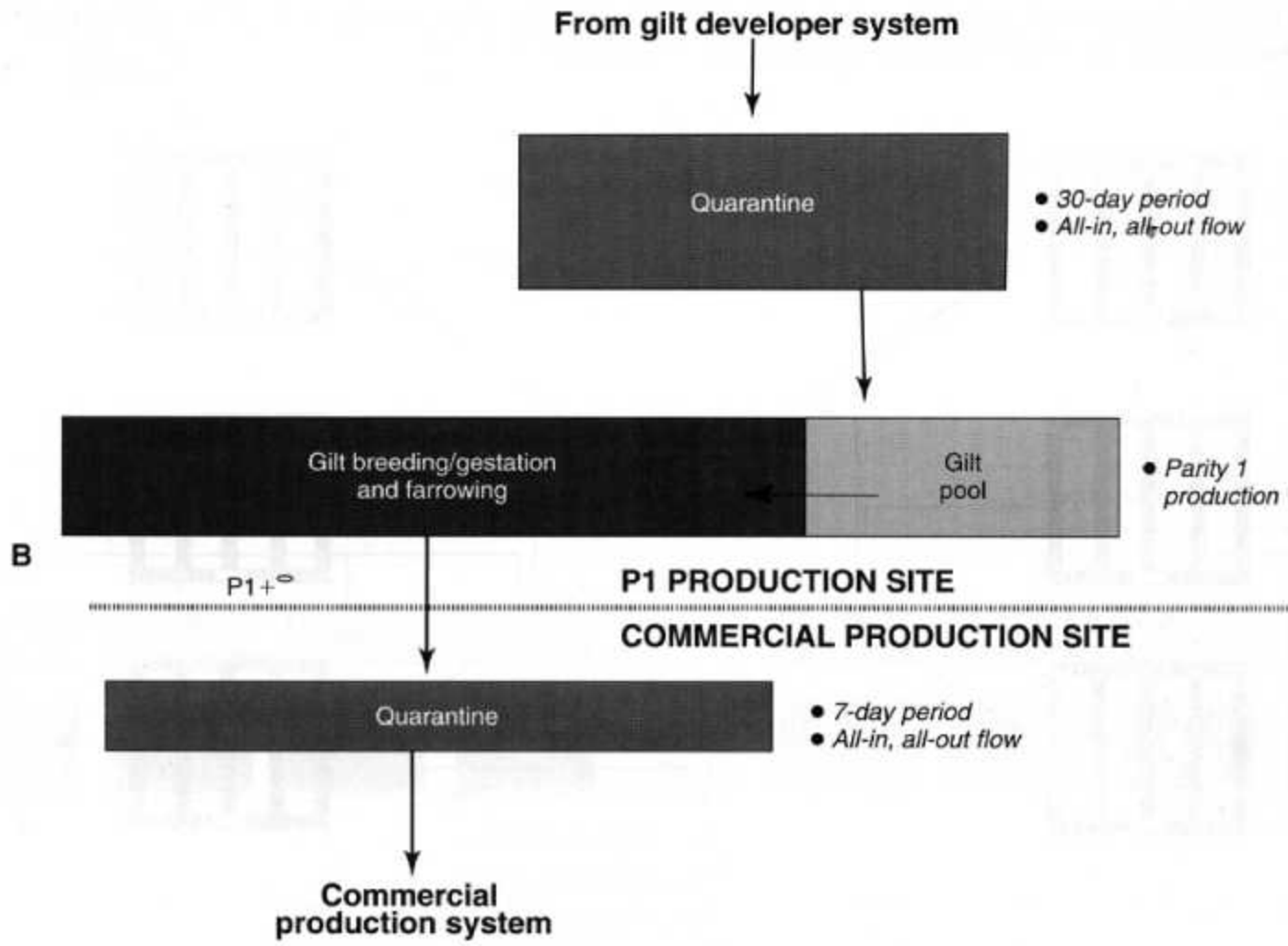


FIG. 15-12 **A,** Gilt development facility: layout and animal flow. **B,** Parity 1 production and commercial production facility layout and animal flow.

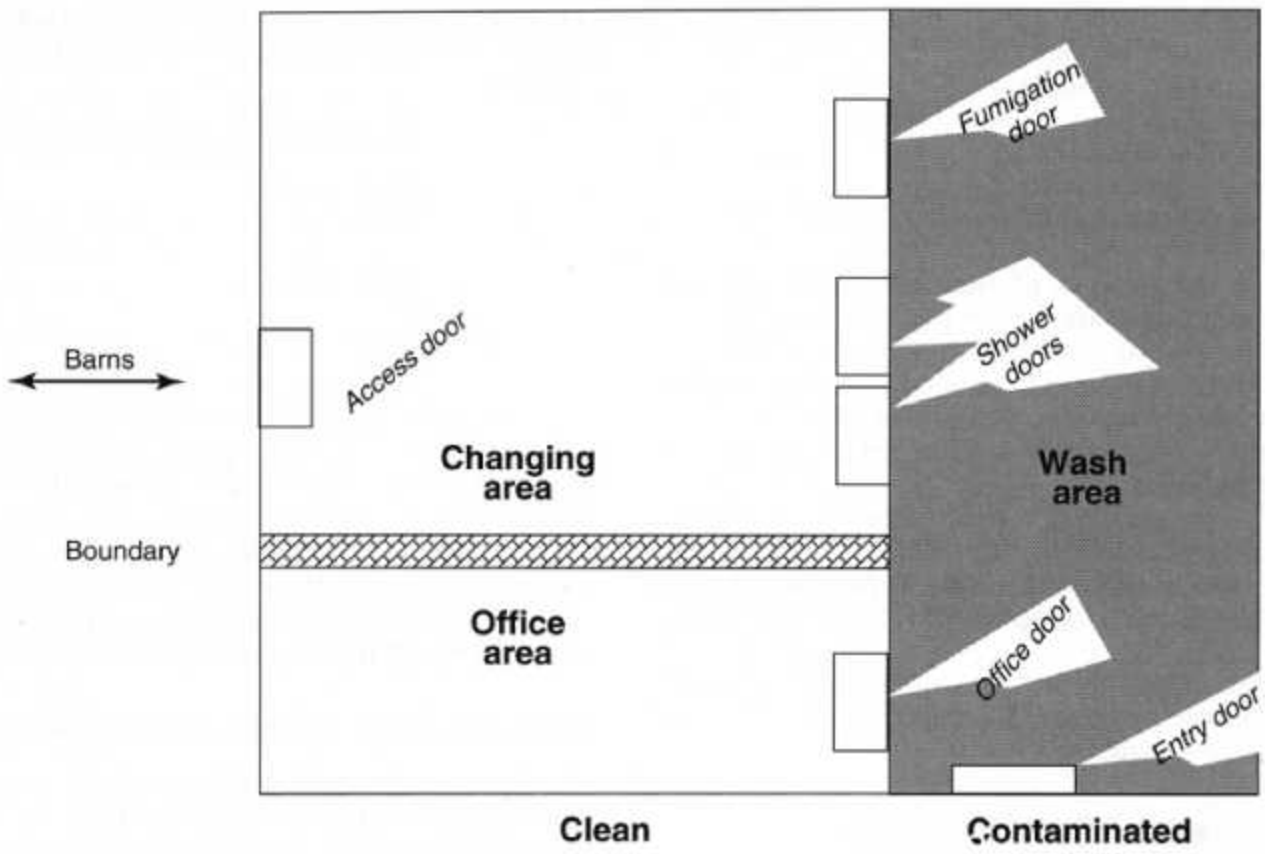


FIG. 15-13 Example of a farm office layout.

Laboratory and Monitoring Protocols

A central veterinary laboratory services the entire production system. The laboratory, located on a neutral site, contains a necropsy area, −70° C freezer, ELISA/PCR capabilities, and a bacteriology laboratory capable of aerobic and anaerobic culture. Testing of quarantine facilities proceeds as just described. All breeding herds are monitored through the weekly testing of piglets during the last week of lactation. Piglets should originate from randomly selected litters, with one piglet selected per litter in an effort to sample across parities. Monitoring the weaning-to-finishing population consists of testing a representative sample, at a calculated sample size equally distributed throughout all facilities each site, on a monthly basis.

EMERGENCY ACTION PLAN FOR HERD DISEASE INVESTIGATION

In addition to diagnostic monitoring, all farms within the BPU will be monitored for the onset of clinical abnormalities through the use of an emergency action plan (EAP). The purpose of the plan is to provide a standardized method for dealing with potential health concerns within each BPU. The EAP consists of four steps:

1. Early detection of an infectious disease
2. Quantification of its spread
3. Accurate diagnosis of its etiology
4. Rapid communication of its presence throughout the system

The EAP is designed so that veterinarians and farm managers can quantitatively assess the spread of peracute infection within specific pig populations. The EAP is based on two parts: *recognition of the problem* and *quantification of the problem*. An example of an EAP used in the industry today is outlined here.

Part 1: Recognition of the Problem

The first part of the EAP is based on the ability of farm personnel to recognize the early signs of an infectious disease process. The EAP divides a swine operation into three distinct populations:

- Breeding/gestation/lactation (B/G/L)
- Nursery (N)
- Finishing (F)

For the purpose of standardization across all farms, specific *clinical categories* have been established. The definition of each category is as follows:

- *Category 1:* inappetence (anorexia, fever)
- *Category 2:* respiratory (coughing)
- *Category 3:* intestinal (diarrhea with or without blood, vomiting)
- *Category 4:* systemic (septicemia, central nervous system, sudden death)

An understanding of these categories, and a daily regimen of monitoring to detect the clinical entities included in each category, must be communicated effectively during the employee training programs and consistently monitored during herd visits. The protocol of daily assessment is as follows:

Step 1. Each population is assessed daily, concentrating on attitude, consumption of feed, fecal consistency, and piglet quality. The following protocol is followed in each room:

1. Alleyway inspection
   - Examination of resting animals
   - Observation of clinical signs
2. Pen inspection
   - Examination of active animals
   - Observation of clinical signs
   - Inspection of water flow and feeder adjustment
   - Feed teasing

Feed teasing is the process of manually placing small handfuls of feed in random spots on a pen floor and observing the animal response. Normal, healthy animals frequently come forward to inspect the feed, whereas suspect animals typically remain inactive and uninterested.

Step 2. Rectal temperatures should be taken of any animal suspected of being ill.

Step 3. Each suspect animal is defined as a *Case*. For example, an anorexic sow is a *Case* within *Category 1*. A coughing finishing pig is a *Case* within *Category 2*, five nursery pigs demonstrating clinical signs of septicemia are 5 *Cases* within *Category 4*.

Step 4. After examination of each population, the number of cases within each category is relayed to the herd veterinarian for quantification.

Part 2: Quantification of the Problem

An example of problem quantification is as follows:

Step 1. The total number of cases over all four categories is calculated for each population. If multiple sites exist, each site represents a population. If a sufficient number of cases are detected in one finishing site, the EAP is activated, even if the other sites are clinically normal (Table 15-11).

TABLE 15-11

Criteria for Activation of Emergency Action Plan (EAP)

Population Inventory	Percent Level of Intervention	Required No. of Cases to Activate EAP
250	2.0	5 ± 1
500	1.5	8 ± 1
750	1.2	9 ± 1
1000	1.0	10 ± 1
1250	1.0	12 ± 1
1500	1.0	15 ± 1
1750	0.85	15 ± 3
2000	0.85	17 ± 3
2250	0.75	17 ± 3
2500	0.70	18 ± 3
2750	0.65	18 ± 3
3000	0.65	20 ± 5
3250	0.60	20 ± 5
3500	0.60	20 ± 5
3750	0.55	20 ± 5
4000	0.50	20 ± 5

Calculation: 1% Level = (1000 × 1%) = 10 ± 1 cases required to activate EAP.
Conclusion: EAP activated.

Step 2. An example of how to calculate the required number of cases-population for initiation of the EAP is as follows:

Population = B/G/L1000- sow inventory)

No. of Cases	
Category 1	16 (8 anorexic lactating sows)
Category 2	0
Category 3	0
Category 4	1 (sudden death)
Total	17

Obviously, the judgment of the veterinarian plays a major role in the decision making process. The veterinarian has the authority to activate the EAP even if the interference levels are not met if judgment dictates it is necessary. It is hoped that the protocol of daily assessment and a standardized method of quantifying clinical impact will heighten the sensitivity of disease detection and enhance effective communication between the farm and the veterinarian.

Protocol of Diagnostic Investigation

Should the EAP require activation, the protocol of diagnostic investigation (PDI) is implemented. In order to manage a disease outbreak, it is critical to obtain an accurate diagnosis, therefore sampling collection and handling is critical. Box 15-5 is an example of a PDI that follows a system-based approach.

Plan of Action After Detection of Disease

If the etiological agent of an infectious disease is conclusively detected, the BPU is designed for immediate action. If an individual weaning-to-finishing complex is infected, depopulation can be implemented. If infection is detected in the quarantine area through the introduction of infected seedstock, the quarantine is also depopulated. Should infection be detected during the 1-week quarantine period between the P1 production farm and the four commercial operations, the infected quarantine will be depopulated and any existing quarantined groups retested. Culling practices within the related commercial farm(s) will be reduced for that individual week of breedings, and plans within the P1 production farm to overbreed in order to compensate for lost production will be initiated.

If infection of the multiplication or P1 production breeding herd should take place, the flow and facility use of the replacement stock program will continue; however, the use of vaccination and acclimation procedures can be implemented immediately. Finally, the fact that the BPU is a "stand-alone" entity and does not rely on animal or personnel farms' other BPUs reduces the spread of infectious disease throughout the entire system of production.

Communication and Data Transfer

All sites within the BPU are electronically linked to the central veterinary laboratory office. Data from each farm, both production and diagnostic, are stored here in a centralized computer database. Results are summarized using the principles of SPC to detect irregularities in data over time throughout the system.

The inability to control diseases such as PRRS by relying solely on the principles and techniques of production has been frustrating. Therefore the advent of new systems and designs for the new millennium must stress the importance of health first, then assess its impact on production. Swine

BOX 15-5

System-Based Protocol of Diagnostic Investigation Approach

REPRODUCTIVE TRACT DISEASE

Serology

1. Collect sera from affected sows (n = 10)
2. Collect sera from nonaffected sows (n = 5)
3. Record ear tag identification and retest 2 to 3 weeks later
4. Test for the following pathogens:
   - Porcine reproductive and respiratory syndrome virus (PRRSV)
   - Aujeszky's disease virus (ADV)
   - Porcine parvovirus (PPV)
   - *Leptospira* sp.
   - Swine influenza virus (SIV)

Tests used are as follows:

PRRSV (ELISA); ADV (ELISA); PPV (hemagglutination inhibition; [HI]) *Leptospira* microscopic agglutination test (MAT); SIV (ELISA) (H1N1/H3N2).

Tissues (Abortion)

1. Collect fetal tissue from 3 to 5 litters, selecting 1 to 2 fetuses/litter.
2. Collect placental tissues from 3 to 5 affected sows.
3. Submit fresh and fixed (10% formalin) tissues.
4. Fetal samples to submit should include: brain, heart, lung, liver, spleen, kidney, stomach fluid, thoracic fluid.
5. Mummified fetuses should be submitted intact. A fetal crown–rump length of <17 cm indicates fetuses of <70 days gestational age.

Direct immunofluorescence for antigen to PRRSV, PPV, ADV, *Leptospira* sp., and SIV (H1N1,H3N2) should be requested, along with bacterial culture, virus isolation, and microscopic examination.

Tissues (Premature farrowings)

Collect 1 to 2 weak suckling piglets from 3 to 5 litters and euthanize. Tissue collection should mimic that described for aborted fetuses; however, it should also include alveolar macrophage lavage for PRRSV isolation.

RESPIRATORY DISEASE

Serology

Respiratory outbreaks should be assessed using the technique of cross sectional or serial testing. Cross-sectional testing consists of a random sampling of animals from different stages of production. Serial profiling consists of ear tagging of individual animals and retesting them over time. Cross-sectional profiling is advantageous because the results are generated much more quickly; however, serial testing demonstrates the presence or absence of seroconversion.

Outbreaks of pneumonia should be investigated based on the following protocol:

Breeding herd

Collect the following samples:

10 clinically affected sows

5 nonaffected sows

Record ear tag identification; retest 2 to 3 weeks later.

Tests

PRRSV (ELISA) *Mycoplasma hyopneumoniae* (ELISA), ADV (ELISA), SIV (H1N1/H3N2) (ELISA), or HI, porcine respiratory coronavirus blocking (ELISA), *Actinobacillus pleuropneumoniae* complement fixation (pooled antigen).

Nursery pigs

Collect the following samples:

Age (weeks)	No. of samples
4	10
6	10
8-10	10

Tests: as above

Finishing pigs

Collect the following samples:

Age (weeks)	No. of samples
10-12	10
14-16	10
18-20	10
22-24	10

Tests: as above

Tissues

Fresh and fixed tissues should be collected as previously described. Tissues collected should consist of lung, lymph nodes, tonsil, spleen, liver, and kidney. Direct immunofluorescence for PRRSV, ADV, SIV, and coronavirus should be conducted. Samples should also be assessed for PRRSV using immunohistochemistry. Attempts to isolate PRRSV should also be a part of the routine diagnostic workup; therefore alveolar macrophage lavage should be collected and tissues should be maintained at −40° C to maximize virus survival. Finally, bacterial culture and microscopic examination of fixed tissue are also required.

INTESTINAL TRACT DISEASE

Serology

Cross-sectional or serial testing is helpful for determining the epidemiology of the infection in the postweaning population. Serological profiling protocols for intestinal problems should consist of coronavirus differential for detection of seroconversion to transmissible gastroenteritis virus and immunofluorescence antibody (IFA) testing for *Lawsonia intracellularis*.

Tissues

Tissue samples are of primary importance in cases of intestinal disease. Frequently gross or microscopic exam is sufficient to determine the cause; however, bacterial culture of agents such as *Salmonella* sp. or *Serpulina hyodysenteriae* enhances the diagnostic process. Other techniques such as impression smears can be helpful for identifying *Isospora suis* merozoites or the large gram-positive rods typical of *Clostridium perfringens*. For further identification of this latter organism, toxin testing should be requested to identify the presence of toxin type A or C.

CENTRAL NERVOUS SYSTEM DISEASE

Outbreaks of nervous system disease are causes for concern, primarily because of the risk of ADV infection. Samples to collect include cerebrum, cerebellum, medulla oblongata, and tonsillar tissue. Fixed and fresh tissues should be collected, and bacterial culture, microscopic examination, and immunofluorescence testing is required. Cerebrospinal fluid can also be collected and is an excellent source of bacterial culture (e.g., *Streptococcus suis* or *Haemophilus parasuis*).

practitioners throughout the world are in an ideal position to lead the process of reeducating the global industry concerning the importance of health. Veterinarians must continue to develop new, creative strategies, first to understand the disease process, second to control its spread, and finally, to minimize its impact.

REPRODUCTIVE PERFORMANCE IN THE SWINE HERD

Reproductive performance has long been considered economically important to the swine producer. Present methods of intensified swine production have created an increased awareness of the influence of reproductive performance on overall production efficiency.

Sow Productivity

Reproductive efficiency of a sow herd is the result of many separate and interacting factors. Sow productivity is dependent on the number of piglets born live, the survival of pigs to weaning, the rebreeding interval, and the conception rate at first and any repeat service. Improved sow productivity is dependent on management during gestation; management at farrowing; management during lactation; management at weaning; management at mating, including the judicious use of hormonal therapy to induce estrus; and appropriate culling. The greatest improvement in the rate of pigs per sow per year results from increasing both the number of pigs born alive and their survival to weaning. Proper feeding of the sow during gestation and lactation is critical for maximum sow productivity. Managing the weaned sow properly to stimulate prompt return to estrus can shorten the farrowing interval and increase annual productivity.

Swine units have become larger and more specialized, and investment in buildings and equipment has increased greatly. Confinement production has placed increased demands on reproductive performance, created new problems to be solved in order to maximize reproductive efficiency, and made precise scheduling extremely important in the operation of an efficient swine production unit. Delays in breeding create major problems in efficient use of facilities and equipment.

The best indicator of reproductive efficiency in breeding herds is *the number of pigs weaned per mated female per year,* which depends on the *number of litters per mated female per year* and the *number of pigs weaned per sow.* It is optimized by the decrease of *nonproductive days, lactation length, number of stillbirths per litter,* and *preweaning mortality,* and by the increase in litter size.

Characteristics of High-Performing Herds

The productivity characteristics of high-performing commercial swine breeding herds have been compared with lower ranking herds (Koketsu et al, 1999; Koketsu, 2000). High-performing herds have shorter lactation durations and higher mean breeding female inventories than other herds. Large herd size likely makes it economically feasible to employ specialized workers, and shorter lactations enables herds to improve facility use. High-performing herds also have better reproductive efficiency and use farrowing facilities more effectively than other herds. High-performing herds had a higher percentage of sows bred by 7 days after weaning than did the remaining herds for all seasons and for all parities except for parity ≥6. Thus high productivity of the high-performing herds is attributable, in part, to better mating management. Higher percentages of multiple matings and sows bred by 7 days after weaning are associated with higher farrowing rate and greater litter size. The lower preweaning mortality rates for high-performing herds, compared with the remaining herds, suggested that these herds provided better piglet care during lactation and better farrowing facilities. Low preweaning mortality rate is associated with the use of supplemental heaters, non-concrete floors, and frequent cleaning and disinfection. In high-performing herds, lactation length was significantly associated with pigs weaned per sow but not associated with litters mated per female per year. High-performing commercial herds could increase pigs weaned per sow by improving preweaning mortality rate and number of pigs born alive, but number of litters per mated female per year was already maximum. For other herds, shortening lactation interval duration would likely decrease farrowing interval and improve efficiency of the reproductive cycle without reducing litter size. The study did not consider farm profitability, sustainability, or sow longevity.

The effects of within-farm variability in the number of females mated per week during a 52-week period on annual productivity have been examined (Koketsu et al, 1999). Increasing within-farm variability in number of females mated per week decreases annual reproductive efficiency, as determined on the basis of number of pigs weaned per mated female per year, farrowing rate, and farrowing interval, but not on number of pigs per litter. Farm managers should determine a target range for the number of females mated per week to prevent large week-to-week variations in breeding herd operations.

With the widespread use of three-site production, and especially all-in, all-out production, it became necessary to reevaluate the reproductive performance requirements in the production systems. The aim of reproductive units in the systems is to provide a low-cost consistent stream of quality progeny. The sow unit is essentially a fixed-cost part of the enterprise that aims to keep its customers' facilities full. The diagnostics of reproductive performance involves determining whether that aim is achieved efficiently.

Sow Longevity in Herd

Reproductive efficiency improves with herd life. Females with higher parities at the time of removal from the herd had weaned more pigs per year in the herd than did females with lower parities (Lucia, 1999). The initial reproductive cycles of young females are critical in determining herd life. Reducing the entry to first service interval would help to minimize the proportion of herd life spent in nonproductive days. Lifetime reproductive and financial performance is optimized among swine herds that have higher proportions of high-parity females (Lucia et al, 2000).

Breeding Records and Targets of Performance

Herd records provide the opportunity to monitor, diagnose, and provide guidance in correcting breeding herd problems. As in any production process, the aim of the breeding herd is to produce the required output in a timely and predictable manner. For instance, the target of a 500-sow herd may be to produce a group of 200 pigs with a minimum weight of 11 pounds and a maximum age of 26 days every week. In some ways, the sow herd can simply be viewed as an input similar to a feedmill to keep the growing pig facilities full. The breeding herd records allow the farm to do the following:

- Monitor activities on the farm to ensure that these targets can be met based on historical production parameters. This allows correct design of facilities and cashflows and assesses the risk of instability in output.

- Predict problems in the output. For instance, a decrease in conception rates can predict that the expected outcome is probably not going to be attained.
- Retrospectively diagnose problems in the design and management of the herd. It is this third area in which veterinarians spend most of their time examining, whereas the other two bullet points are predominately the efforts of the swine herdsman.

If the targets are not being achieved, several methods are available to reduce the analysis to the level of possible causal relationships. Some of the relationships can be elicited from normal herd records, whereas others must be based on discussion or further analysis. A basic methodology is as follows:

1. Are the pigs that come out of the farrowing crate meeting specifications? Lactational difficulty, infectious disease, and excessive competition among piglets may be found in records if they are kept in detail, but, in most cases, this involves the recollection of the farrowing room manager along with the observations of the swine veterinarian. Furthermore, mortality and morbidity records are almost invariably biased by the views of the record-keeper.
2. Is the sow herd inventory optimum for the facilities and the production methods? Often the sow herd inventory must be compared with the productivity of the herd and the facility capacities. Piglet inventories are also required to examine in detail exactly how the farrowing rooms are being managed and the amount of transfer between rooms. Nonetheless, it appears that many breeding herds, unless they are contractors, actually have a less than optimum breeding herd inventory.
3. What are the nonproductive sow days, on average, over the period of concern? Nonproductive sow days are, essentially, all the sow days in which the sows are not lactating or gestating. Thus nonproductive sow days contain the entry to mating interval for gilts, the mating to successful service interval, and the weaning to estrus interval in weaned sows as well as the weaning to removal interval in sows that are culled. With record-keeping systems such as PigCHAMP, these individual components can be defined and analyzed in more detail.
4. What is the average litter size over the time of concern? This is a more basic index than open sow days but does involve an accurate definition of stillbirths and sow inventory.

It is important to consider that there can be various biases in the indexes just described. First, many farms are reluctant to record gilts until they are successfully mated. This may then involve recording gilts only if they are mated. This will reduce the gilt inventory on the record-keeping system and decrease the actual capacity for additional sows in the gestational facility. Second, there may be a bias toward recording sows, not when they are actually culled, but when they are functionally no longer part of the herd. Thus, in some cases, the culling date is based on the culling decision instead of on the shipment date. In other cases, there may be a bias toward what is often called "retrospective culling" in which, when a sow returns, it is culled at its breeding date. Third, in some herds, to increase litter size, there are "phantom sows" (ones that are in the herd but not recorded) that can be used to inflate the reproductive performance while keeping the herd size artificially low.

The open sow days are directly inversely proportional to the litters per sow per year within the management scheme of a farm. Litter size and litters per sow per year vary by a number of factors to allow further analysis. The most common methods to further examine the data are by parity and by time. These two factors can create much of the description of the functional changes occurring in the herd. Parity affects both of these variables, and the treatment of individual parities often affects the breeding herd performance. For instance, second parity dip is often a function of excessively large litters on gilts. This can be examined by comparing the net foster number between parities on a parity report in PigCHAMP. Alternatively, graphing of litter size and various components of open days can be used on a calendar basis to show the effects of changes in management. For instance, if the weaning-to-culling interval increases after the introduction of a new breeding herd manager, this may be a sign for further investigation.

It should be emphasized that, especially in smaller herds, it is difficult to be certain of the trends based on the sample sizes available. Basing changes in production methods on 20 of the previous litters with a reduction in one pig per litter is probably unwise. Alternatively, if undesirable production practices are known to occur in the herd that should be changed to ensure continued success on the farm, this may be the justification to go forward with some of these.

Not all answers can be derived from reading herd records. The other way of using herd records to diagnose breeding problems is to make it a teaching moment board for further discussion with the producer. This is especially useful when production or other parameters are converted into graphs. This often jogs the memory of the farmer but also induces the farmer to open up and give more detail into the concerns and methods that are currently being used on the farm. It can also be used to give guidance and further analysis by either inducing more detailed production records or perhaps even creating an experimental protocol on that farm.

When a sow is moved into a farrowing crate or a farrowing pen, there is an expectation that the sow will farrow within a short time, producing a large number of pigs that are large, active, healthy, and able to convert the available colostrum and milk into rapid growth. It is expected that the sow will produce sufficient colostrum and milk and begin to ingest adequate amounts of feed and water to maintain herself and her progeny. The sow should have the ability to lie down in such a manner to protect the piglets. Preferably, all the sows within a group will farrow at the same time to allow efficient cross-fostering.

Measures of Reproductive Performance

The basic measure of success is the number of piglets weaned per week and secondarily the efficiency in achieving that flow of pigs. Secondary expected levels of efficiency include the following:

1. *Total number of services.* The number of services compared from week to week should be approximately equal to maximize continual flow through of the barn and thus utilization of the facilities. The number should exceed the target services per week to achieve the target number of pigs weaned per week.
2. *Percent repeat services.* A general rule of thumb is that if more than half the proportion of sows that do not farrow are bred again, culling based on poor reproductive performance should be emphasized. Sows are much more likely to return and tend to have smaller litters.
3. *Percent multiple matings.* If the level is below 85%, more time should be spent in the breeding room observing sows as they come into estrus to allow them to be bred more often.
4. *Weaning to first service interval and percent sows bred by 7 days.* To use the breeding room to its maximum, it is advantageous to have a 7-day turnover; the best sows are those that return within 7 days. Thus the weaning to first service interval on average should be below 7 days and percent sows bred by 7 days should be at least 85%.

5. *Average number of pigs born alive per litter.* With a normal parity distribution and the capabilities of most of the genetic stock and management procedures, an average number born alive of 10.5 to 11 can normally be attained.
6. *Average number of pigs born dead per litter.* To achieve a high average of pigs born alive per litter, the number of pigs born dead must be minimized with a percentage born dead being below 5% and the percentage of mummies being below 1%.
7. *Farrowing interval.* The farrowing interval should be below 150 days to allow for a large number of litters to be produced per sow per year. This can be compared against the potential farrowing interval, which is the average gestation length plus the average lactation length plus a 5-day weaning to breeding interval.
8. *Preweaning mortality.* This can be decreased to 10% through a rigorous monitoring of pigs. Preweaning mortality is closely related to the number of pigs born dead in many herds.
9. *Adjusted 21-day weight.* This is a good measure of the milking ability of the sows; if there is large variation, nutritional and other management factors should be examined closely. An aim is to produce 13-lb pigs at 21 days.
10. *Culling rate.* Most established herds should have a culling rate of at least 40% to maintain a constant herd profile for parity. This depends on a high average parity of culled sows. If either the average parity of culled sows is lower than 3, this should be examined closely and the age increased, or the culling rate accepted should increase to prevent receiving old sows.
11. *Sow mortality rate.* Sow mortality is a major cause of economic loss, since it involves unscheduled loss of sows, and often progeny; replacement costs for gilts are high.

For precise up-to-date indicators of herd performance, it is necessary to identify and extract specific data from those records related most closely to sensitive stages and events in the breeding cycle. The number of analyses and their frequency and detail depend on such factors as size of unit, degree of personal involvement by management, and overall production figures. A large herd with a poor production record, for example, may benefit from frequent and detailed record analysis, at least until the problems have been resolved. Sometimes it may be necessary to carry out in-depth analysis of data pertaining to a specific problem area to characterize it fully and, if possible, to identify any causal relationships.

Factors Influencing Reproductive Performance of Sow Productivity

The reproductive performance of sow productivity in a swine herd is dependent on several identifiable factors. The number of piglets weaned per sow per year is a function of the farrowing interval, the entry to farrowing interval for gilts, and the litter size at weaning.

The number of piglets weaned per sow per year can be increased by reducing the interval between farrowing or entry and conception and by reducing the lactation period. The length of gestation is almost constant, but it can be decreased by 2 to 4 days by the induction of parturition, although this is rarely recommended. Litter size can be enlarged by increasing ovulation and conception rates or by reducing losses in the perinatal and postnatal periods.

The major factors that affect reproductive performance in swine include the following:

1. Number of pigs born alive per litter
2. Pubertal development, first estrus, and anestrus in gilts
3. Weaning-to-estrus interval and delayed estrus in sows
4. Management and assessment of reproductive performance of boars
5. Mating management of gilts and sows
6. Pregnancy losses: failure to conceive, embryonic mortality, fetal death and abortion or fetal mummification, and stillbirths.
7. Perinatal mortality: low birth weight of piglets, small litters, low viability of piglets' disease, and lactational failure.

Number of Pigs Born Alive per Litter

The number of live-born pigs per litter is directly related to sow productivity. A reduction in live-born piglets per litter causes a reduction in pigs weaned per sow per year. During the past 50 years in the United States, the mean number of pigs weaned per litter has remained nearly constant at 7.4 pigs. With a preweaning mortality estimated at 18% of live-born litter size, an estimate of live-born litter size at 9.3 pigs/litter is much less than the estimated potential litter size of 10.5 to 11 pigs (Clark and Leman, 1987). The factors that influence litter size in pigs have been reviewed (Clark and Leman, 1986a,b). Surveys of swine farms in Ontario found that the herd-level variables associated with litter size included: the method of estrus detection, the number of matings per sow, the number of sows farrowing per week, the identity of the breeding manager, and the amount of time devoted to estrus detection and breeding sows (Dewey et al, 1995a).

The factors that influence litter size have been divided into two major categories (Clark and Leman, 1986a,b). The first category includes parity, age at conception of the first litter, number of matings per conception, season, previous lactation length, previous weaning-to-conception interval, and breed. These data are often recorded by commercial swine producers and are available for retrospective studies. The second category includes husbandry practices, nutrition, disease, and the contribution of the boar. Data for the measurement of the effects of these variables on litter size are not usually available in record-keeping systems.

Litter Size and Parity. Litter size is usually smallest in parity 1; increases to a maximum size in parities 3, 4, and 5; and then remains nearly constant or slowly declines as parity increases (Clark and Leman, 1986a,b). Age at conception, number of matings per conception, season of conception, and breed size have been associated with variation in parity 1 litter size, but the associations varied among herds (Clark et al, 1988). In some herds, as age at first conception increased, litter size increased slightly. On a herd basis, changing the breeding of gilts to their first observed heat can cause a reduction of one pig/litter compared with breeding them on the second or third heat.

Litter Size and Sow Management. The associations between litter size and specific sow-level management factors in a sampling of Ontario swine farms that used computerized recording systems showed a curvilinear relationship between litter size and parity; the largest litters were from sows in parities 3 through 10 (Dewey et al, 1995a,b). Natural matings resulted in one more pig/litter than did AI. Lactation length of 27 to 32 days and 33 to 40 days caused progressively larger litter sizes in subsequent farrowings than shorter lactation lengths. Litter size was highest at weaning-to-conception intervals of up to 4 days, decreased daily from 5 to 7 days (at which point it reached a plateau), until Day 11 when it increased again. The sow's current litter size was positively associated with her previous litter size.

Litter Size, Ovulation and Fertilization Rate, and Embryonic Mortality. Litter size is determined by ovulation rate, fertilization rate, and embryonic mortality. Despite a high ovulation rate of about 17, and fertilization rates from

90% to 95%, about 35% of fertilized ova and fetuses are reabsorbed or aborted during pregnancy. Average litter size at term is about 10 piglets; however, a significant number of litters are much smaller, and embryonic reabsorption accounts for more than one half of the total variation in this number in intensive swine herds. The majority (30%) of embryos dies within the first 40 days of gestation, followed by an additional reduction of 10% to 20% by term; embryonic mortality is a significant factor in determining litter size at farrowing. Pig fetuses require a certain initial length of the uterus to implant, develop, and survive. Length of uterus appears to be an important factor in limiting litter size as the number of ovulations increases (Wu and Dziuk, 1988). It is thought that there is limited capacity of the porcine uterus, and that as the fetus and placenta develop in gestation, some fetuses become crowded and die. An increase in the incidence of mummified fetuses in large litters is associated with uterine space per fetus below that needed for development and survival. A 12% fetal loss in late gestation can be associated with low uterine space per fetus. A longer uterus provides a greater space per fetus, a larger number of live fetuses, and a lower incidence of mummies. Average litter sizes can be increased substantially by reducing conceptus losses during early pregnancy through management practices such as restricted feed intake during the first weeks of pregnancy in order to maximize embryonic survival (Stone, 1987).

The effects of disease on litter size in pigs can be categorized into four major groups: (1) fertilization failure, (2) whole-litter loss, (3) small live-born litters with increased numbers of stillbirths and mummified fetuses, and (4) small live-born litters without increased numbers of stillbirths and mummified fetuses.

Litter Size and Nutrition. The influence of nutrition on ovulation rate has been reviewed extensively, and it has been established that increasing feed or energy intake before mating (e.g., flushing) increases ovulation rate (Aherne and Kirkwood, 1985). However, whereas higher ovulation rates in gilts are usually associated with an increased number of embryos, they are also associated with increased embryo mortality. Flushing in the prepubertal period does not enhance piglet production in gilts mated at puberty.

Although dietary manipulation has not been shown to have an effect on litter size, the absolute intake, particularly during farrowing and the weaning to estrus interval, has shown an effect. Low feed intake has been shown to decrease subsequent litter size, particularly if it occurs during late lactation (Zak et al, 1997).

Litter Size and Length of Lactation. Changing the length of the lactation of sows of parity greater than 1 can also result in a decrease in litter size (Mabry et al, 1996). There can be a difference of 0.2 piglet/litter between sows whose piglets are weaned at 20 days versus 15 days. In Ontario swine farms, litter size increased progressively at previous lactation lengths of 20, 25, 27, and 33 days (Dewey et al, 1994). Sows bred on Days 2 to 4 after weaning had essentially the same litter size. Litter size decreased progressively for sows bred on Days 5, 6, and 7 after weaning and then reached a plateau until it increased again for sows bred on Day 11 or later.

The reduction in litter size with earlier weaning is not caused by a reduction in ovulation rate but by increased losses of embryos, which suggests that the uterus requires a minimum period of time to fully recover from the previous pregnancy.

The length of lactation may influence subsequent litter size. A reduction of weaning age from Day 42 leads to a concomitant reduction in litter size (Clark and Leman, 1986a). The mechanism is associated with high plasma levels of estradiol after weaning. Estimates of optimum lactation length to achieve maximum reproductive efficiency range from 21 to 28 days. Some observations indicated that early weaning at 21 ± 3 days had no effect on subsequent litter size when the weaning-to-conception interval was longer than 14 days (Clark and Leman, 1986b). In those sows with weaning-to-conception intervals of less than 14 days, litter size was reduced by 0.1 pig for each day between the mean weaning ages of 21.9 and 27.5 days. Therefore the effects of lactation length on litter size are likely influenced by the weaning-to-conception interval. Investigations of the records of 11,929 litters from five commercial herds indicated that the preceding farrowing-to-conception interval had a positive effect on litter size from parity 3 to parity 7 sows (Clark and Leman, 1987). Live litter size per sow per year can be optimized if the farrowing-to-conception interval is manipulated by duration of lactation and culling to achieve a mean farrowing-to-conception interval of 35 days in parity 3 through parity 7 sows (Clark and Leman, 1987).

Litter Size and Number of Matings. Litter size may increase with increased matings per conception in some herds and not in others. The length of estrus in sows is about 66 hours, and ovulation occurs about 40 hours (range, 36 to 50 hours) after the start of estrus. A single mating at the optimum time during estrus would be expected to achieve maximum litter size. The optimum time is considered 12 hours before ovulation. Because there is no outward sign during the 66-hour estrus period to indicate when ovulation occurs, the pig's response to back pressure has been used to predict the time interval during which ovulation would be expected. Gilts exhibit the standing reflex only after direct exposure to the boar in the first and last 11-hour periods. During the middle 44-hour period, the gilts exhibited the standing reflex for the boar and for the inseminator. Litter size and conception rate were shown to be maximized when gilts were mated once by AI 22 or 33 hours into the estral period. Litter size was found to be reduced severely when insemination was performed 11 hours earlier or later (Clark and Leman, 1986a). Unless sows are mated during the optimum period, litter size is affected by the number of matings per estrus. The more matings per estrus, the greater the opportunity to mate the female during the 10- to 20-hour period before ovulation, which has been shown to maximize litter size. However, it has been shown that insemination during late estrus decreases litter size (Rozeboom et al, 1997).

One alternative that many farms use to ensure large weaned litter size is to farrow more sows than fit in the farrowing room and to cross-foster these extra litters onto the sows. This increases litter size and allows sows to be culled upon weaning at Day 0. If farrowing facilities are expensive, this may be a rational alternative in many cases. Litter size is controlled by many other factors at lower frequencies, such as infectious disease, zearalenone in the feed, and irregular feeding. Nonetheless, it is often difficult to determine the causes of small litter size, especially in short runs. Although shortcuts in swine husbandry can be taken, care in the factors mentioned is needed to maintain some assurance that litter size will remain acceptable.

Litter Size and Genetics. It is generally accepted that litter size cannot be increased through genetic selection because litter size has a heritability of about 0.1 and a coefficient of variation of about 0.25. However, intense selection based on several litter records indicates that prolificacy can be increased by exploiting within-population variability. There is some evidence that selection for components of litter size, namely ovulation rate and embryo survival, may have some potential. Even though rapid genetic responses in litter size are theoretically possible by conventional selection systems, the inclusion of litter size in selection has only moderate effects on overall economic gains because of the importance of growth rate and carcass traits. Based on the

genetic gains estimated from the analyses of several hundred litter records at an experimental station, it is proposed that litter weight at 21 days, alone or in combination with litter size at 21 days or the number of live-born piglets per litter in an index, can be used as the primary selection criterion to obtain genetic improvement in sow productivity traits. There is some heterosis effect on litter size. Genetic selection has had some increase on litter size through the choice of hyperprolific females (Ollivier, 1990). Some breeding stock suppliers have included a highly prolific Meishan line from China in their breeding stock development as well.

Pubertal Development, First Estrus, and Anestrus in Gilts

Maintenance of an optimum litter size at birth and an increase of the overall efficiency of the breeding herd offer two good opportunities for ensuring a productive swine unit. Because 30% to 40% of the sow herd is replaced by gilts each year, introduction of gilts into the breeding herd is an important aspect of herd productivity. The intensification of pig production has altered the physiological patterns and physiology of gilts, which has necessitated that producers establish gilt pools to increase the probability of cyclic gilts for breeding. However, the maintenance of large pools of gilts to have enough gilts in estrus at the right times causes increased feed, labor, and housing costs. Therefore every economical management effort must be made to improve gilt reproductive efficiency.

Pubertal Development. The attainment of puberty, continuation of regular estrous cycles, ovulation rate, and embryonic survival are the most important aspects of gilt reproduction. Effective early induction of puberty in the gilt has become important to swine producers, because it reduces the cost of gilt replacement in the breeding herd. The factors that influence sexual maturation, puberty, and reproductive efficiency in the gilt have been reviewed (Dyck, 1988b). Sexual development of the gilt involves the three distinct phases of sexual maturation, attainment of puberty, and pregnancy (Dyck, 1988b).

The developmental changes associated with sexual maturation are an orderly sequence of hormonal and anatomical changes that lead to puberty. A resting period follows this process until puberty. Extensive research on the occurrence of puberty—the point in time when the gilt commences regular estrous cycle activity—has shown that there is considerable variation in the mean age at puberty among breeds, breed crosses, lines within breeds, and locations. The variation in age at puberty remains constant with an SD of approximately 20 days for the western swine breeds. This translates into a range in age of 120 days with 68% of the gilts in estrus over a 40-day interval and 95% in estrus over an 80-day interval (Dyck, 1988a). Although it is not possible to substantially reduce age at puberty except by selection, puberty can be delayed by dietary intake restriction and by confinement housing with no movement or exposure to mature boars. Chronic feed restriction of gilts can cause cessation of estrous cycles in gilts. When gilts are moved and exposed to mature boars, they will be in estrus in a short period, if they have attained sexual maturity.

Pubertal or First Estrus. Pubertal estrus is expected in most gilts between 6 and 8 months of age. The natural range in the attainment of puberty is from 135 to 250 days; this range is due to various stimulatory and inhibitory influences, including genotype, nutritional status, environment, and the presence or absence of the boar (Hughes and Varley, 1980). With such a range, it is hardly surprising that the introduction of gilts into a breeding program in a herd is difficult to manage. The failure or delay of gilts reared under total confinement to exhibit a detectable estrus is one of the most common causes of inferior reproductive performance in swine.

The need to plan, predict, and control estrus in groups of cycling gilts has emerged from structural changes in the pig industry. The more the operation is out of phase with the sow-culling program, the greater the economic losses. If the breeding of gilts becomes erratic, overall production fluctuates 4 to 6 months later, with a major deleterious effect on cash flow. Conversely, if gilts are not available when needed, there is a propensity to keep sows that should be culled.

After the gilt attains puberty, it enters the next stage of the reproductive process, which includes conception, pregnancy, and parturition. To achieve the birth of a large, uniform litter of piglets, it is necessary to maximize ovulation rate, pregnancy rate, conception rate, and embryonic and fetal survival and growth, and to minimize death losses. Research on the many facets of pregnancy has resulted in development of nutritional and mating management procedures to maximize ovulation, pregnancy, and conception rates. The failure of gilts to continue to cycle at the desired time of breeding is associated largely with the time of year when they attain puberty. Anestrus in gilts is lowest when day length is increasing (e.g., winter and spring) and highest during the summer months when day length is decreasing. However, there has been little change in litter size at birth.

Anestrus in Gilts. The causes of anestrus include immaturity, the stress of confinement by tethering or individual stalls, the absence of a boar near the gilts, the breed of the gilt, and the failure of management to detect estrus behavior in the gilt. Gilts raised in confinement have delayed puberty and either quiet estrus or behavioral anestrus. Total confinement can reduce the proportion of gilts that attain puberty by 8 to 9 months of age by up to 50%; time of year may also affect the onset of puberty.

The proportion of gilts that do not show regular estrous cycles at 9 months of age ranges from 10% to 40%, and the line of the gilts is an important factor contributing to this percentage. Of noncyclic gilts slaughtered at 9 months of age, 55% were gilts with immature reproductive tracts, indicating delayed puberty; 45% were gilts with fully developed uteri and ovaries that had corpora lutea at different stages of development or preovulatory follicles and corpora albicans, indicating behavioral anestrus or an inability by herdsmen to detect estrus.

Various techniques have been used to stimulate the onset of regular estrous cycles in the gilt. These include daily exposure to a mature boar at the time of puberty, purposeful transportation of the gilts to stimulate the onset of estrus, and hormonal therapy. The exposure of prepubertal gilts to a boar advances the onset of first estrus. The timing of initial boar exposure has been shown to be of major importance; the gilt age at the start of boar exposure regulates the response obtained to a large extent. Boar exposure at a very young age (e.g., 3 to 4 months) or at a later age (e.g., 6 months or older) is inefficient. However, exposure of the boar to the gilts at about 160 days of age leads to the highest incidence of onset of regular estrous cycles. Continual boar contact with groups of gilts at this age results in 80% to 88% of the gilts ovulating within 17 days. The first estrus is usually followed by a second and third estrus at 18- to 21-day intervals. The gilts may then be bred on the second or third estrus for optimum ovulation rate. It is also known that olfaction plays an important role in porcine reproductive processes. Acceleration or delay of puberty can be affected by the presence or absence of mature boar odor.

The environmental stimulation of transportation has been considered as a possible technique for initiating estrus in gilts. It has been commonly observed that gilts come into

estrus a few days after being transported. However, controlled field trials indicate that the transportation was not a significant factor in inducing estrus in gilts (Stephens and Close, 1984). The close proximity to adult breeding stock was more important than transportation and relocation.

The role of nutrition as a factor influencing age at puberty has been studied extensively. In general, when the nutrient supply is adequate for commercially acceptable growth rates, there is no effect on age to puberty, but some suggest that a minimum adipose-to-lean tissue ratio is required for attainment of puberty (Kirkwood and Aherne, 1985).

Hormonal Induction of Estrus. Hormonal therapies to initiate the onset of estrus in gilts include the induction of ovulation with either pregnant mares' serum gonadotrophin (PMSG) or human chorionic gonadotropin (HCG), the imposition of a new estrus rhythm using HCG, the destruction of corpora lutea using either estrogens or progesterone, and the suppression of estrus and ovulation using either progesterone or analogs of progesterone (Kirkwood, 1999). The most promising method appears to be that of suppression of estrus and ovulation. Groups of randomly cycling gilts are treated with an agent to maintain all of the animals in a state of midcycle quiescence. Withdrawal of the treatment is followed by a rapid follicular phase, and the gilts come into heat all at the same time.

Allyl-trenbolone, a progestogenic compound, is an effective heat-synchronizing agent in gilts. The use of either allyl-trenbolone or gonadotropin (400 IU PMSG and 200 IU HCG) was effective in the control of estrus and ovulation in groups of prepubertal gilts (Varley et al, 1989). Evaluation of allyl-trenbolone fed during late lactation to primiparous and multiparous sows showed no significant benefit on their subsequent reproductive performance. Altrenogest, a synthetic progestogen, when fed for 10 days, can also effectively synchronize groups of gilts. A reliable synchronizing agent would provide considerable scope for planned mating of groups of gilts. The breeding of large numbers of gilts in a short period requires considerable planning of boar management to ensure that a sufficient number of highly fertile boars is available.

Anestrus resulting from inactive ovaries may be treated with a combination of 400 IU PMSG and 200 IU HCG. Approximately two thirds of the animals will exhibit estrus in 7 to 10 days, but the fertility level and number of pigs born alive are less than that for normally bred gilts. However, it may be useful as a temporary therapy when matings are needed for that week.

Weaning-to-Estrus Interval and Delayed Estrus in Sows

At the time of weaning after a 42-day lactation, the reproductive tract of the sow resembles that of a prepubertal gilt or anestrous sow (Dyck, 1983). From weaning to Day 6 (e.g., estrus) the ovarian vesicular follicle population changes from predominantly small follicles on the day of weaning to large preovulatory follicles, a few medium-sized follicles, and a large number of small follicles by Day 6 after weaning (Dyck, 1983).

The factors that affect the weaning-to-conception interval in sows include endocrine activity, uterine changes, genotype, parity of the sow, season of the year, and level of nutrition during the preceding lactation. Under ideal conditions the sow usually exhibits estrus within 7 days after her pigs have been weaned.

Postweaning anestrus in sows may be due to any one or a combination of the following:

- True anestrus resulting from failure of ovulation
- Silent estrus with normal ovarian activity
- Failure of the herdsperson to detect estrus because of mismanagement

The latter two causes are difficult if not impossible to differentiate. Slaughterhouse examinations of the ovaries of sows culled for anestrus reveal the presence of corpora lutea in about 50% of primiparous and 80% of multiparous sows, which indicates that silent estrus and failure to detect estrus are major causes of anestrus. The ovaries of postweaning anestrus sows are not inactive (Rojanasthien and Einarsson, 1988). Progesterone profiles of postweaning sows reveal that 90% of multiparous and 68% of primiparous sows resume ovarian activity within 10 days. Ovulation with overt estrus within 10 days occurs in 46% of primiparous sows and 54% of multiparous sows. Ovulation without detected heat may occur in 30% of all sows during the first 10 days after weaning.

The season of the year has a significant deleterious effect on return to the regular estrous cycle; this effect is more severe in primiparous sows than in multiparous sows. Postweaning anestrus is most common between July and October, which may be associated with the change in length of daylight. These observations have been recorded in the United Kingdom, Australia, and North America.

Underfeeding during lactation and after weaning, particularly in primiparous sows, is considered a significant cause of postweaning anestrus. Approximately 50% of primiparous sows fail to exhibit estrus within 1 week of weaning, whereas almost 80% of older sows are mated within this period. Inadequate nutrition of sows during their first lactation and the associated body weight and fat losses have been implicated as major factors affecting the incidence of postweaning anestrus. Lactating sows, particularly primiparous sows, are often unable to consume sufficient quantities of feed to satisfy their requirements for energy and protein. There is a critical level of energy intake during lactation, below which the weaning-to-estrus interval is adversely affected by low-energy intake, even when protein intake is adequate. However, protein intake during lactation may exert a greater influence on the interval between weaning and estrus in primiparous sows than does energy intake. The substantial nitrogen loss sustained by lactating sows with low protein intakes is the primary nutritional factor responsible for the prolonged weaning-to-estrus interval of primiparous sows. Age and body weight are also important; primiparous sows that are older and heavier at farrowing exhibit estrus earlier than younger sows, even when body weight losses during lactation are greater in the older sows.

Earlier weaning causes a reduced conception rate, increased cystic ovarian degeneration, and a net reduction in sow productivity. The weaning-to-breeding interval can influence ovulation rate (Deckert et al, 1997). The uterus requires 14 days to return to its normal size and weight after farrowing and an additional 10 days before it is ready to accept further implantation. Zero-weaning of sows (e.g., within a few hours of birth) causes an increase in the interval from farrowing to conception, a concomitant increase in the farrowing interval, an increased incidence of cystic ovarian degeneration, and a reduced conception rate compared with sows that have their pigs weaned 30 days after delivery.

Practical Recommendations for Management of Anestrus. The minimization of the mean interval from weaning to mating is of paramount importance if maximum sow productivity is to be achieved. As general guidelines, anestrus sows can be defined as problems if they do not show estrus before 7 days after weaning, and gilts can be defined as problems if they are not detected in heat and bred by 8 months of age. The most important management procedure to minimize the incidence of delayed estrus after weaning in sows is to move the sow to a breeding barn

specifically designed for housing sows from weaning until successful breeding and conception. After weaning, sows may be placed in individual stalls or in groups of four to six and observed carefully twice daily for the first 10 days after weaning. An intense surveillance system of heat detection in the recently weaned sow is necessary. Boar contact should begin within a few days after weaning to detect estrus in any of the sows. Sows in heat should be bred under supervision and a repeat service carried out in 12 to 24 hours. Bred sows should be identified and observed 18 to 21 days later for any returns to heat.

Hormonal therapy has been advocated for the treatment of sows with prolonged postweaning anestrus. PMSG at 400 IU combined with HCG at 200 IU may induce a fertile estrus within 7 days after treatment in about 66% of animals (Kirkwood et al, 1998). A comparison among exogenous estradiol benzoate, gonadotropin-releasing hormone (GnRH), PMSG, and HCG indicated that only PMSG was effective in inducing a fertile estrus in sows affected with persistent anestrus. Prostaglandin analogs in combination with GnRH are not as successful. A combination of estradiol benzoate and HCG is also ineffective.

The induction of ovulation and conception in lactating sows has been examined as a possible method of reducing the overall mean farrowing interval. Treatment with PMSG at 1500 IU, followed 96 hours later by HCG at 100 IU and followed 24 and 36 hours later by AI, will induce ovulation and conception as early as 15 days after farrowing. The conception rates, number of corpora lutea, and average number of embryos obtained were comparable to those obtained in a natural breeding program. The sow can be inseminated successfully without interruption of lactation or removal of piglets; pregnancy is thus concurrent with lactation, eliminating the need for early weaning and reducing the interval between successive farrowings. It is not possible to synchronize estrus in the pig with two doses of prostaglandins at a fixed interval as is possible in the cow.

Seasonal (Summer) Infertility. Seasonal or summer infertility occurs in swine herds in many parts of the world. In intensive herds in southern European countries, the United States, and Australia, seasonal infertility is induced by heat stress. This type of infertility is characterized by a decrease in farrowing rate and a delay in the return of sows to estrus after mating. There are increases in the number of sows showing irregular returns to estrus after service. Litter size is not adversely affected, but gilts and primiparous sows are most frequently affected. Depressed fertility in boars also occurs. It is thought that this type of infertility is caused by heat stress imposed more than 7 days after mating, which causes whole-litter loss and the return of the sow to estrus. In Britain and some other northern countries, there is an increase in sow abortions in the autumn, particularly in September and October. The lower levels of serum progesterone in pregnant sows in the autumn months may suggest a pathophysiological mechanism for this type of infertility. However, factors other than heat stress can cause reduced infertility in a swine herd at any time of the year. The effects of different photoperiods are controversial (Gooneratne and Thacker, 1990). These observations are important in the management of swine-breeding farms and in the diagnosis of reproductive problems. The provision of shade and the sprinkling of water on sows, gilts, and boars during the hottest periods of the year have been recommended and may be beneficial. The effects of seasonal infertility may be minimized by intensifying postservice estrus detection from 17 to 35 days after breeding, especially during the heat-stress periods. Early diagnosis of pregnancy should be made by 35 days after breeding so nonpregnant females either can be returned to the breeding area for surveillance or can be culled.

The fertility in sows mated during the low fertility summer season can be significantly improved by the addition of oxytocin (4 IU) to the seminal dose immediately before AI (Pena et al, 1998).

Practical Recommendations to Improve Breeding Herd Productivity. To improve breeding-herd productivity on swine farms, it is recommended that producers change their management systems to decrease lactation length, the percentage of gilts in the breeding-female inventory and female culling rate, and increase the percentage of multiple matings (King et al, 1998).

Management of Reproductive Performance of Boars and their Growth, Development, Selection, and Use

The prepubertal development of boars reared in herds exerts a major influence on the level of sexual behavior of the boar. Physical contact with other pigs is a critical aspect of the social environment, and producers should ensure that breeding boars are reared in an environment that allows physical contact with other pigs. The social environment after puberty also has a marked influence on the level of sexual behavior of the boar. A stimulus or stimuli from the female pig appears to be necessary to maintain the potential level of sexual behavior of the mature boar. The mature boar also requires stimulation from the presence of female pigs, regardless of their estrus stages, to maintain his potential level of sexual behavior. It appears that olfactory and, to a lesser extent, auditory stimuli are responsible for this effect. The development of the sexual behavior of the boar is dependent on the integration of androgens and estrogens, which act synergistically to maintain the growth and development of the accessory organs and secondary sexual characteristics (Booth, 1988). The pheromones, secreted by the testis and transported by the submaxillary gland to the saliva, facilitate the rigid standing reflex of the estrus pig so that the boar can more readily breed.

Boars should be purchased from reputable herds that will delineate the exact guarantee and the condition under which the boar will be replaced. Only boars older than 8 months of age should be guaranteed, and breeders should void the guarantee if the new owner does not follow recommended boar management practices. Before a new boar is delivered, it should be tested serologically for diseases such as leptospirosis, brucellosis, pseudorabies, and other endemic diseases that can be detected serologically (Lord et al, 1997). Ideally, newly introduced boars should be kept in isolation for at least 2 weeks, then mixed with nonpregnant breeding females about 1 month before use in breeding to promote the spread of infectious agents, such as parvovirus and porcine enteroviruses, well before breeding to ensure that immunization occurs. During this preconditioning period, boars should be test mated by exposure to females in heat. Boars should be purchased at least 6 weeks before the beginning of breeding to allow for a 2-week quarantine and a 4-week preconditioning period. They should be at least 8 months old before routine use.

Assessment of Reproductive Performance of Boars. There is little published validated information on methods for the assessment of reproductive performance of boars. Several studies indicate that a boar has an influence on subsequent litter size, whereas others could not document a consistent boar effect (Clark et al, 1989). A large number of litters are required to detect litter size differences attributable to boars, which precludes the use of litter size as a criterion for culling boars. Semen characteristics vary widely among the different ejaculates of each boar and have little association with litter size. The conception rate of sows bred

by boars varies considerably among boars but is confounded by variations in conception rate caused by matings per conception, season of the year, parity, nutrition of the sow, and duration of lactation. The identification of subfertile boars early in their reproductive life, so that they can be replaced early, has not been achieved.

The farrowing rate of the females bred by the boar has been evaluated as a measure of fertility of boars. The first 100 single-boar services of 140 boars were analyzed to determine if the farrowing rate from initial services could reliably predict the farrowing rate of subsequent services. The farrowing rate of less than 50 initial services of boars cannot be used as a reliable estimate of farrowing rate for subsequent services through 100 farrowings, and therefore it cannot be used as a management aid for culling subfertile boars. Boars should not be culled because of poor initial performance as measured by farrowing rate, which is influenced by parity, number of matings per estrus, and season of service. The results indicated that increased numbers of sows should be bred in the summer, more gilts than needed should be bred, sows of parity 8 or more should be culled, and all females should be mated at least twice per service to avoid reduced farrowing rates. Other workers feel that farrowing rate of first service is superior to percentage of returns to service as a method of monitoring performance of boars, provided the recorded farrowing dates are compatible with the recorded first service. The percentage of returns to first service provides information rapidly and may allow the identification of gross infertility in an individual boar. However, sows that do not conceive at first service may not be recorded because of failure to detect estrus, failure to record the fact, or anestrus.

The following indexes for the assessment of the reproductive performance of boars have been suggested:

- Ratio of boars to sows of 1:20
- Age at first breeding of 7 to 8 months
- Average number of services per week at 7 to 9 months of age of two/week
- Average number of services per week at 9 to 12 months of age of three to five/week
- Average number of services per week at older than 12 months of age of six/week
- First service conception rate of 90%
- Average interval to return to estrus of sows bred of 21 days
- Average litter size of 9.5
- Percent of litters with less than eight piglets of less than 15%
- Time since last service of less than 1 week

Boar-to-Sow Ratio. The number of boars required to achieve optimum fertility depends on the age of the boars, the size of the breeding pens, and the desired mating system. Ideally, young boars should not be used more than once daily. Because the mating of each female two or more times increases conception rate and litter size, there should be enough breeding boars to mate each female twice. The number of boars needed is equal to the maximum number of females in heat per day × 2.

Mating Systems. Double mating can significantly increase conception rate and subsequent litter size. Maximum conception rates are obtained when females are mated approximately 12 hours before ovulation. Much of the benefit gained from double mating may be the result of breeding nearer to the optimum time. Double mating can be achieved either by mating at 12- to 24-hour intervals with the same boar or with two different boars. In a hand-mating program, after the first mating, the female is served again, either later the same day or on the following morning. In the commonly used pen-mating system, double mating can be achieved by twice-daily boar rotation.

Culling of Boars. An effective culling policy for boars is part of a successful breeding management program, but the reasons for culling boars and an economic target value for an annual culling rate of boars has not been determined (D'Allaire and Leman, 1990). The estimated lifetime breeding expectancy of boars in a commercial swine herd varies from 12 to 24 months but can range from 0.3 to 38.5 months. In a study of boar culling in 84 herds in Minnesota over a period of 12 months, the annual culling rate was 59% and the proportions of reasons for culling were overweight boars (47%), reproductive problems (18%), leg problems (12%), death (7%), and other diseases (4%). The average breeding life was estimated at 20 months. Such a culling rate is considered too high, but there are few standards for comparison. The high rates of culling for overweight boars may reflect a feeding management problem, which indicates that the nutrition status and feeding program of the herds should be reviewed and corrected as necessary to improve the longevity of boars.

Artificial Insemination. AI has become an integral part of pig production, particularly in large herds. AI can be applied to swine production to increase the possibility of genetic improvement, disease control, and intensive management. The most critical problem in breeding sows artificially is determining the correct time to breed. Ovulation occurs approximately 40 hours after the beginning of standing heat, and the ova remain viable for only 1 to 2 hours. Therefore maximum conception is achieved when fresh spermatozoa are waiting to fertilize the ova as soon as they leave the ovary. Ideally, a sow should be inseminated early on the second day of standing heat to ensure that fresh, viable sperm are ready to fertilize the ova. However, with variation in sows and the fact that most producers only check for heat once daily, sows are usually bred on the first and second days of standing heat to ensure the maximum conception rate (Glossop, 1998).

A major constraint to the development of AI in swine is that boar semen freezes poorly, and prolongation of the viability of semen beyond the fourth day is a problem (Cosgrove, 1997). Long-term extenders are being developed that should allow the use of semen for more than 3 days and perhaps up to 9 days. The success of these long-term extenders will depend on the selection of boars with the best semen, with high suitability for long-term storage.

Boar ejaculate is characterized by its large volume (around 300 ml on average) and spermatozoa number (80 to 120 billion when semen is collected once a week), which corresponds to total sperm reserves and widely exceeds daily sperm production (10 to 20 billion spermatozoa/day). As a consequence, spermatozoa number per ejaculate steadily decreases when the boar is used or collected more than once per week, in spite of a slight increase in sperm production with ejaculatory frequency. Large amounts of spermatozoa and semen are necessary to ensure normal conception rate and prolificacy (50 ml of semen and 3 billion sperm are considered minimum requirements for AI). Frozen boar semen can be used successfully, but it leads to much lower conception rate and litter size than fresh semen so that its commercial use is currently very limited. These circumstances limit the use of either natural service (sow/boar ratio cannot exceed 12 to 15) or AI boars (which produce about 1000 semen doses per year) and consequently the dissemination capacity of favorable genes in breeding programs.

The technique of insemination is relatively standardized. During estrus, a sow is normally inseminated twice with 3 to 5 billion sperm in 40 to 80 ml of extender, although the later insemination is not as important if the first insemination is timed correctly.

Errors in insemination technique result in poor reproductive output, inefficient use of resources, or both. The choice of extender, boar usage rates, semen concentration, processing technique and insemination techniques are all in a tension between cost control and acceptable reproductive productivity.

The challenge for the veterinarian is mainly to assess the effect of insemination on farrowing rate and litter size. Swine producers now purchase semen from boar studs. These studs can have boar inventories as large as 300 boars. Semen is delivered 3 days a week or more, depending in part on the relative distance to the stud and the frequency of weaning.

Poor insemination technique or semen quality results in lower farrowing rates, more nonproductive sow days (NPSDs), and lower litter size. The specific faults may include the following:

- *Timing*. Excellent estrus detection is needed to make AI a useful technology. Inefficient detection results in late insemination or missed opportunities to mate sows. This causes lower litter size, farrowing rates, and more NPSDs. This problem is particularly acute in gilts, since estrus is more difficult to predict and detect (Soede et al, 1995).
- *Inseminator technique*. The inseminated sow needs to be stimulated adequately to induce contraction of the uterus to deliver the semen to the fallopian tubes. These contractions draw the extended semen from the bottle or sachet and are indicators of a successful insemination. Stimulation can include the presence of a boar or boar odors, backpressure, and kneading the flanks. Real differences can often be found among insemination technicians, and training and discipline in technique is important. In addition, adequate time should be given to employees to ensure good technique (Crabo and Dial, 1992).
- *Age and storage of semen*. As fresh semen ages, especially in less than optimum storage, the reproductive efficiency rapidly decreases. The exact expected parameters depend on the extender used, as do the storage conditions. In general, semen should not be used after 5 days of storage, and use after 3 days should be minimized.
- *Processing technique*. Boar stud management includes caring for the boar, collecting the semen, evaluating the ejaculate, and extending and packaging the semen. There are numerous errors that are possible, but most common problems are contamination of semen through contaminated equipment. This is in spite of the regular addition of broad-spectrum antibiotics in the extended semen. Viruses that exist in the ejaculate of infected boars are spread easily and thus disease control is imperative (Philpott, 1993).

AI is, as is any production technology, susceptible to error. However, it has been readily adopted as technique on swine farms. When AI is used correctly, productivity has increased and many costs have decreased.

Numerous diseases of swine can be transmitted by using fresh or frozen semen for AI. Information on this subject has been reviewed (Philpott, 1993). Contamination of semen with bacteria, mycoplasmas, rickettsiae, and viruses can occur within the boar, during collection, at processing, and during storage and transport. Infections of the reproductive organs of the boar can cause contamination of the semen. During collection of the semen, contamination may occur because of uncleanliness of the operator or the use of dirty equipment. Methods used to minimize bacterial contamination of semen include hygienic collecting and processing of semen, isolation of boars from certain pathogens, and the addition of antimicrobials to the semen. Many viruses have been isolated from semen, including PRRSV, Aujeszky's disease virus, PPV, enterovirus, adenovirus, reovirus, Japanese B encephalitis virus, apthovirus, SVD virus, and ASF virus. It is believed that there is a greater risk of infection from the introduction of an infected boar into a herd than from the use of fresh or frozen semen. AI permits breed improvement with the least risk of disease transmission.

Mating Management of Gilts and Sows

Maximum reproductive efficiency begins by breeding gilts at an early and predictable stage so that they farrow a good-sized litter at 10 to 11 months of age, nurse the pigs well, and maintain moderate body weight to ensure an early return to heat after weaning. They should proceed to produce good-sized litters approximately every 150 to 160 days up to about the sixth litter, with weaning programs at 4 weeks of age. Factors that influence the age at which gilts reach puberty include genotype, nutrition during the growth period, contact with boars, and stresses associated with transportation and commingling with other gilts. Gilts are usually selected at approximately 170 days of age, mixed with other gilts, and given short periods of supervised daily contact with a boar. Following this stimulation, groups of gilts will usually exhibit their first standing heat in 6 to 10 days. The second and third heats will usually follow in a synchronized fashion, and flushing (i.e., increasing the level of feeding 10 days before the breeding heat) can be done to increase the ovulation rate.

The factors that influence successful rebreeding of sows after weaning include the following:

Feeding. Sows should be fed a high level of feed from farrowing until mating to ensure that they come into heat as early as possible, preferably within 5 to 7 days. The feed intake must be reduced immediately after mating, because high feed intakes after mating increase embryonic loss, especially in gilts.

Housing. Following weaning, sows are usually housed in individual stalls or groups. There are advantages and disadvantages of both systems. In individual stalls, estrus detection may be more difficult than when sows are in groups. However, when sows are grouped, fighting can be a major problem. Fighting and riding during estrus leads to increased lameness and culling. Feed intake can be controlled more effectively in stalls than in groups, and feed intake can be reduced after mating. The housing system should allow for comfort; easy detection of heat; sight, smell, and sounds of the boar; easy movement of sows to the boar; and a good service area. It should also provide ease of movement and safety for herdspersons.

Parity. Sows are more difficult to breed successfully after their first lactation. This is usually associated with excessive weight loss of the gilt during her first pregnancy and lactation. As parity increases, the weaning-to-conception interval decreases. Excessive weight loss during the first lactation can be minimized by increasing feed intake during the lactation period or reducing litter size by cross-fostering.

Selection of a Farrowing Cycle. The complete reproductive cycle of mature swine involves mating, gestation, farrowing, lactating, weaning, and the interval to remating. Adequate facilities must be available to accommodate a number of animals at each of these stages. Farrowing time is relatively inflexible, and the parturition–nursing unit requires the greatest investment of capital. Therefore it is advisable to plan the entire reproductive program to optimize use of this facility. Batch farrowing allows better organization and more efficient use of facilities and labor and reduces disease problems in newborn piglets. In a batch-farrowing system, groups of females bred at about the same time move into a farrowing unit just before the first sow is due, remain in the unit until the youngest litter reaches weaning age, and then

are moved into the rebreeding area. The farrowing room is completely cleaned and sanitized before the next group moves in. The length of the farrowing cycle or time that the group occupies the farrowing room can be as short as 4 weeks with early weaning but is usually 5 to 6 weeks in most commercial practices.

In a herd that practices 4- to 5-week weaning, sows should be moved into the farrowing crates 3 to 4 days before they are due, and 1 or 2 days will be required for cleanup as the litters are weaned. Therefore the farrowing room will be tied up for 6 weeks with each batch. If 250 litters are expected, this requires 250 × 6, or 1500 crate-weeks, or a total of 28.8 crates. This could be organized with two farrowing rooms of 15 crates each operating with a farrowing every third week, or with three rooms of 10 crates each operating on a 2-week cycle. Both systems can spread the farrowing, weaning, cleanup, and rebreeding uniformly throughout the year.

In a 3-week cycle, 15 sows will be weaned; 12 of these should conceive the following week. The herdsperson should attempt to mate four or five gilts at the same time to maintain a batch of 15 pregnant animals. With a 2-week cycle, 8 of the 10 weaned animals should conceive the week after weaning, and about three additional gilts should be mated to maintain the batch number. Additional gilts must be mated if some of the group is culled before remating. The advantage of the 3-week cycle is that females that fail to conceive at first mating usually return during the period when the next group is being mated. However, working replacement gilts into the system is easier with a breeding every second week. Larger units with populations in excess of 125 sows should consider batch-farrowing a group of sows every week.

Whatever system is adopted, it should be organized to produce a uniform flow of batches through the mating, gestating, and farrowing areas and then back to the mating area for rebreeding. To achieve efficient breeding performance with batches over prolonged periods necessitates adequate housing, sound nutrition, and a disease control program that maintains the entire herd in continual good health. In addition, the operator must plan and execute a management routine that ensures prompt initiation of estrus after weaning, detection of estrus, high pregnancy rates, and large litters.

Predicting Number of Pigs Weaned Weekly. The even flow of pigs through a herd is important for several reasons. The producer must make optimum use of existing facilities to control the fixed costs of production. If there are excess number of pigs being produced with insufficient barn capacity, the pigs become crowded. Overcrowding can decrease feed intake and average daily gain and may increase the incidence of disease. A steady flow of pigs produced has become a high priority in segregated early-weaning production systems in which the nursery operator expects a given number of pigs per week to fill the nursery. Profits for the sow producers depend on production of a steady supply of pigs each week.

A spreadsheet can be used to predict the number of pigs weaned per week 19 weeks after the sows are mated (Dewey et al, 1997b). The prediction is based on 3-week rolling averages of sows served and 12-week rolling averages of litter size, preweaning mortality, and farrowing rate. It is possible to predict the number of pigs weaned per week as soon as the numbers of sows mated during a 3-week period are known.

Pregnancy Diagnosis. The recurrence of estrus following service is a traditionally accepted method of diagnosing nonpregnancy in sows (Almond and Dial, 1987). In large herds where sows are penned individually, the detection of heat can be difficult and unreliable. The commercial gain through the routine use of pregnancy diagnosis is dependent on the accuracy of the results, the overall fertility of the herd, and the costs of the test. It has been suggested that in higher performance herds with a consistent farrowing rate of 85%, ultrasonic pregnancy testing at about 1 month after the first service may be uneconomical, and that more attention should be given to improved detection of sows returning to estrus (Meredith, 1989). Returns to service are a more sensitive measure of fertility, because most nonpregnant sows will return in the first month and not reach the stage of pregnancy testing. Proponents of pregnancy testing argue that nonpregnant sows will be detected earlier, and the costs of barren sows will be reduced. However, the counterargument is that the cost of keeping a barren sow has been overestimated. The real question is how many empty days can be saved by pregnancy testing? In theory, nonpregnant sows can be identified by pregnancy testing at 1 month after service rather than waiting to be identified as a return-to-heat or a not-in-pig (NIP) sow later. However, in real practice, pregnancy testing will not be done routinely, and many sows will not be tested until they are well past the earliest day they could have been examined. When they are examined, it is unlikely that they will be culled if they are negative because most negatives will be false-negatives; culling a false-negative can be costly.

The principles, applications, and accuracy of pregnancy diagnosis in swine have been reviewed (Almond and Dial, 1987). There is no ideal technique available, and the method of choice varies with the requirements of the individual user. The available techniques include detection of estrus with boar exposure, estrus enhancement with estradiol-testosterone injections on Days 19 and 20 after breeding, laparoscopy, and serum concentrations of prostaglandins, progesterone, estrone sulfate, radiography, rectal palpation, vaginal biopsy, and ultrasound.

The ideal pregnancy test should be highly accurate (e.g., >95%) and should have low prevalences (e.g., <5%) of false-positive and false-negative results (Almond and Dial, 1987). The test should be safe, simple, and inexpensive and should provide results within a few minutes. It should be possible to conduct the test and receive the results before a nonconceiving animal is likely to return to estrus (e.g., <21 days). The test should be applicable to animals that are 1 week or more apart in gestation, so that a test can be conducted on all animals in a group at the same time. The test should also require a low investment of labor.

The most commonly used technique is the observation of the sow for failure to return to estrus after breeding. It is the oldest, most widely used, and most accurate method for predicting that sows will farrow (Almond and Dial, 1986). This method is based on the premise that pregnant sows rarely exhibit estrus during gestation, and that nonpregnant sows will return to estrus within 18 to 25 days after breeding. The test depends on the attendant making the observation of heat and using the standing reflex posture in response to back pressure; the test results are more conclusive if the sow's behavior is observed in the presence of a boar. Therefore the gestation facilities must be designed to allow daily fence-line contact between boars and sows. Daily estrus detection enables 98% accuracy in predicting farrowing rate if daily boar exposure for estrus detection is provided between 18 and 24 days after breeding. Although increased time and effort are required with this technique, the sow is reexposed to the boar soon after conception fails, thereby minimizing the weaning-to-conception interval. False-positive diagnosis may occur if the sow becomes pseudopregnant. Of sows that return to estrus after breeding, one group will return at a mean of 20 days and the other at 26 days (Glossop and

Foulkes, 1988). The first group represents failure of fertilization and the second group early embryonic death. The failure to detect heat at the first opportunity would lead to a second return at about 41 days.

The accuracies of the mechanical and endocrine tests have been compared with the return-to-estrus method (Almond and Dial, 1986). The overall accuracies of the techniques for diagnosing pregnancy were: returns to estrus, 98%; estrone sulfate, 92%; progesterone, 92%; Doppler with rectal probe, 86%; Doppler with abdominal probe, 86%; diode ruler, 73%; and oscilloscope, 86%. Estrus detection resulted in the lowest incidence of false-positive and false-negative diagnoses.

Mechanical ultrasound devices are used commonly by commercial swine producers for pregnancy diagnosis because they are easy to use, are commercially available, and are perceived as being highly accurate (Almond and Dial, 1987). The Doppler ultrasound device gives optimum results between 29 to 35 days of pregnancy, with an accuracy of more than 85% for pregnant animals and more than 95% for nonpregnant animals. There appear to be no significant differences between the accuracy of the Doppler fitted with the rectal probe and the Doppler fitted with the abdominal probe. With amplitude-depth ultrasound, the accuracy is more than 95% between 30 and 75 days of pregnancy. This method appears to have greater sensitivity but less specificity than the Doppler instruments. The ultrasonic linear scanning instrument (e.g., real-time, B-mode ultrasonography) is more than 95% accurate for determination of pregnancy between 22 to 24 days after breeding.

Rectal palpation is possible in sows but not in gilts, and it has an accuracy rate of about 94% when performed between 30 and 60 days of gestation. Rectal palpation is more than 94% accurate when performed at 28 to 30 days of pregnancy. Accuracy approaches 100% from 60 days to term. It is simple and quick, does not require expensive instruments or laboratory facilities, requires only minimal restraint, and is highly accurate. Sows are examined while standing in their gestation crates or pens or while tethered in the standing position. Where laboratory facilities are readily available, the vaginal biopsy technique is considered more efficient than the ultrasonic technique. Neither system allows routine detection of animals that have failed to conceive before the first anticipated return to service. False-positive results may occur because of embryonic or fetal death. The vaginal biopsy technique is highly accurate at between 18 and 22 days after mating.

An on-farm progesterone assay kit to determine pregnancy in sows claims an accuracy of 95% for pregnancy and 36% for nonpregnancy in sows sampled between 17 to 20 days after service (Glossop et al, 1989).

Pregnancy Losses

Reproductive losses can be grouped broadly into those that occur before breeding, such as those associated with anestrus in sows and gilts, and those associated with problems after breeding. Pregnancy loss is associated with failure of conception, embryonic mortality, fetal death and abortion or fetal mummification, pseudopregnancy, and diseases of the sow. A systematic and logical approach must be used when attempting to make a diagnosis of reproductive failure in a swine herd. The data required to monitor reproductive performance include: sow number; date of birth; date weaned; date bred; parity number; boar used; number of times bred and interservice interval; dates of rebreeding; dates of health events such as abortions, discharges, pregnancy test results, and treatments given; number of piglets born alive and dead; number of piglets mummified and their size; and litter scatter (e.g., the percentage of litters with less than nine total piglets alive and dead). Comparison of actual performance with the targets of performance at each stage of the reproductive pathway identifies the area that needs further epidemiological, clinical, and laboratory investigation.

The major categories of reproductive loss that occur after breeding are as follows:

Failure to Conceive. Failure to conceive is characterized by return to service 18 to 20 days after a normal mating or insemination and may be due to any of the following factors: (1) the spermatozoa fail to reach the ova; this may be the result of an abnormal uterus or occlusion of the oviducts; (2) death of ova postfertilization caused by inherent defects of the gametes, incompatibility between the gametes, or failure of the spermatozoa to penetrate the ova; insemination too early or too late in the estrus cycle or the use of boars with temporary infertility may also be causative factors; (3) death of the developing blastocysts within 12 days of fertilization is usually followed by the sow returning to estrus within the normal 21-day cycle; causes of blastocyst death include overfeeding, environmental stresses, and systemic illness. In the Australian experience, there is a relationship between high summer temperatures, which exceed 32° C, and an increase in the incidence of sows that exhibit delayed, irregular returns to estrus. In Britain, manifestations of seasonal reproductive inefficiency in large breeding units, mainly in animals bred during the months of July and August, include an increase in the returns to service, abortion, and sows remaining barren 95 days after service. Epidemics of endometritis can reduce the conception rate of gilts to about 11% compared with 82% in healthy gilts. Affected gilts have a profuse vulvar discharge that commences 6 days after estrus, and the disease usually resolves spontaneously after one or more estrous cycles. The bacterial species isolated are those that normally inhabit the lower urogenital tract, and it is thought they become opportunists at the onset of estrus. In some situations, medication of the prepuce of the boar, of the sow using long-acting oxytetracycline, and of the feed for 21 days was considered beneficial.

Zearalenone in the diets of gilts or sows may cause reproductive failure associated with uterine and ovarian abnormalities, reduced litter size, infertility, or pseudopregnancy.

Embryonic Mortality. Embryonic mortality is characterized by return to estrus more than 24 days after service. Embryonic loss between 14 and 40 days after fertilization is followed by resorption of the uterine contents. Causes include infections of the uterus occurring at mating or by transmission in semen.

Fetal Death and Abortion or Mummification. Damage or disease in fetuses from 35 days to term can produce various effects, including abnormality of tissue differentiation and function, distortion of body structure, and growth retardation. The onset of immune competence takes place at about 65 to 70 days of gestation, and after this time, antibody production and inflammatory processes can take place. Fetal death is followed by autolysis and then mummification or maceration, if sufficient time elapses before parturition or abortion. Bones of dead fetuses are not usually resorbed; therefore age of death, and sometimes even events that preceded death, can be determined by radiological examination.

The common causes of fetal death in swine are leptospirosis and infection with parvovirus and pseudorabies. Leptospirosis usually causes abortion without any significant illness of the sow. The diagnosis is made by serological examination of the sow and laboratory examination of the fetuses.

Parvovirus infection before 70 days of gestation in nonimmune gilts or sows will commonly cause mummified fetuses, which are carried to term with the net result of a small number of live piglets per litter. Parvovirus infection is widespread in the pig population, but the degree of reproductive failure depends on the number of susceptible females introduced into the breeding herd from outside sources. Maternal immunity must be established before conception occurs. In some surveys, parvovirus infection may account for up to 45% of fetal deaths in swine herds. Outbreaks of reproductive failure may occur after introduction of the infection into a susceptible herd. Severe fetal mummification can be expected in sows that become infected between 45 and 65 days of gestation.

Pseudorabies infection during gestation in nonimmune sows may cause fetal resorption, fetal mummification, and abortion. In some outbreaks, maternal illness occurs before the fetal deaths, whereas in others, there may be no significant illness in the dams. Diagnosis is dependent on examination of the fetuses and serological examination of the dams. Control of the disease may be achieved through the use of an eradication scheme of serological testing and the culling of positive animals or the use of vaccines in susceptible animals at least 2 weeks before breeding.

Other causes of fetal death that may occur sporadically include infections with enteroviruses, reoviruses, adenoviruses, and miscellaneous bacterial and fungal infections.

In some abortions, all of the embryos and fetuses are expelled without obvious abnormalities other than subcutaneous congestion, hemolysis, and early autolysis. On other occasions, however, some or all members of the litter may be diseased or long dead. Careful examination of aborted litters is therefore important not only because it enables distinction between maternal and embryonic failure but also because, in embryonic failure cases, it sheds light on what kinds of disease processes were involved. Radiography may once again be useful to ascertain the ages of the fetuses when they died and to detect abnormalities preceding death. Furthermore, if all fetuses in the litter are radiographed, it may be possible to determine whether all were affected simultaneously on a particular date, as in cases of maternal illness or transplacental toxemia, or whether a sequential process was involved with spread from fetus to fetus in utero, as in cases of certain intrauterine infections.

When fresh fetuses are available, as when pregnant sows are slaughtered specifically for the purpose or in instances in which stillbirths or early neonatal deaths are identified as the major problem, there may be a need for postmortem dissection and perhaps other detailed studies. First, however, the conceptual age of the litter must be ascertained from the service date, and then other quantitative information can be recorded and compared with appropriate standards (e.g., means and tolerance limits) for normal fetuses or piglets of that particular age. Such standards can be of special value in the assessment of the normality of fetal and newborn piglets.

Placentae should be examined when necessary, although recognition of pathological abnormalities presupposes familiarity with the normal placenta.

Stillbirths. Between 5% and 7% of piglets are born dead, and approximately 10% of these die before the act of parturition begins. Most stillbirths occur during the process of parturition because of anoxia caused by premature separation of the placenta or intrauterine rupture of the umbilical cord, which may be shortened. Prolonged parturition or uterine inertia in older sows may also be involved. The presence of meconium on the skin, in the mouth, and in the trachea of the piglet differentiates the type II anoxic intrapartum stillbirth from type I prepartum cases. Deaths that occur during the process of parturition (e.g., stillbirths) often result from fetal asphyxia. Sometimes, however, prior disease renders the fetus incapable of successful transition; therefore careful postmortem study may be needed to ascertain the exact mechanisms of stillbirth. Distinction between late fetal death, intrapartum death (e.g., stillbirth), and early neonatal death is not always easy when parturitions are not actually observed. However, late fetal deaths (i.e., those occurring 24 to 48 hours before term) usually show signs of early autolytic degeneration (e.g., cloudy cornea, subcutaneous and intraabdominal hemolysis, friable liver and kidneys), whereas evidence of lung expansion is seen in cases of neonatal death. Piglets asphyxiated in utero often have meconium and mucus in their tracheas and bronchi.

The majority of stillborn piglets are viable at the time of parturition. Only 10% to 20% of these stillborn piglets are type I. Stillbirths are most common in older sows, in large litters, and in the last piglets born in a litter. The longer the farrowing process, the more likely one or more piglets will be trapped in utero without adequate placental connection and will suffocate. The challenge is to save pigs in large litters in which stillborn piglets are most likely to occur. The risk factors that are associated with stillbirths and can be used to predict which sows will deliver stillbirths are older sows, a previous litter size of more than 12 piglets, and a record of previous stillbirths. If such high-risk farrowings are attended, and if proper guidelines on assisting sows during farrowing are followed, the incidence of stillbirths can be reduced. The induction of parturition with prostaglandins in high-risk sows allows scheduling of parturition during the working day so that adequate surveillance and assistance can be provided.

Perinatal Mortality Losses

Low-Birth-Weight Piglets, Small Litters, Low Viability, and Lactational Failure. Low-birth-weight piglets occur in most litters, especially those that are large and those born to older sows. They are usually associated with small areas of placentation that are established at the implantation phase, particularly where uterine overcrowding has also occurred.

Small litters are usually the result of an above-average degree of embryonic loss. It has been shown that pregnancy will not usually be maintained if four or less conceptuses are present in the uterus in the implantation phase or if one horn is devoid of developing blastocysts. Therefore, when two to five piglets are born, embryonic loss beyond the average has taken place. Reduced litter size may also occur in sows inseminated late or early in the estrous cycle or with the use of subfertile boars or semen that has been delayed in transit.

Low viability can be expected in underweight or overweight piglets or where the number of stillbirths in a litter is higher than normal. If, however, it occurs in apparently normal piglets, other factors are involved. Prenatal virus infection and vitamin A deficiency can be responsible for congenital malformation with subsequent low viability. Pregnancies that are terminated 2 or 3 days early, or those that end at Day 117 or later, also produce this effect. In-breeding, estrogenic mycotoxins, or nutritional inadequacies such as manganese or vitamin B_{12} deficiency may also be responsible for some reduction in viability.

The inherent weaknesses of all newborn piglets, namely the absence of subcutaneous fat, an undeveloped thermoregulating mechanism, and low glucose reserves, contribute to early perinatal loss, particularly if the environmental or nutritional conditions are also inadequate.

Infectious Agents Associated with Reproductive Failure in Swine. The following section reviews the major infectious agents capable of causing reproductive failure in swine.

An understanding of the general terminology of swine reproductive failure is essential for adequate consideration of the subject. The gestation period, or the period from conception to birth (approximately 114 days), can be divided into two sections: the embryonic period and the fetal period. The former usually includes the period from 10 to 30 days after conception, whereas the latter extends from 30 days to birth. The neonatal period consists of birth to 7 days of age.

Embryonic death refers to mortality of the conceptus before calcification of the skeleton that occurs at about 30 days' gestation. If embryonic death occurs before Day 12 of gestation, resorption of the embryos will take place and the sow will undergo a regular return to estrus. Pregnancy failure after Day 12 may cause delayed returns to estrus (e.g., greater than 25 days). Mummification occurs primarily in the fetal period after some calcification has taken place, approximately from Day 30 to 70 of gestation. Mummified fetuses are characterized by death, discoloration, and the resorption of fluids and then soft tissues. Stillbirths are fetuses that have matured fully in utero, but are born dead near the normal end of the gestation period. Stillborn piglets look normal, but their lungs have never inflated. There are two basic types of stillbirths: type I includes fetuses that die before the end of gestation, usually of infectious causes, and are prepartum deaths. Type II are piglets that die during parturition, usually of noninfectious causes, and are known as intrapartum deaths. Examples of the causes of this type of stillbirths are hypoxia resulting from umbilical rupture or impeded umbilical blood flow causing high carbon dioxide and low oxygen tension, high atmospheric carbon monoxide, and high temperatures in the farrowing house (>39° C) during Days 102 to 110 of gestation and prolonged parturition.

Abortion refers to the delivery of an immature fetus before the completion of the gestation period. The fetus is usually dead or dies shortly after birth. Early neonatal death refers to death or extreme weakness of the piglet within the first 7 days after birth. This condition is usually due to events occurring during gestation or soon after birth. Finally, embryos and fetuses may also undergo congenital malformations that are abnormalities in the size, shape, location, or structure of any part of the developing conceptus.

Porcine Reproductive and Respiratory Syndrome Virus (Blue-Eared Pig Disease, Mystery Swine Disease, and Swine Infertility and Respiratory Syndrome

During the late 1980s, outbreaks of a devastating new pig disease were reported in swine herds throughout the United States (Zimmerman et al, 1997). Clinical signs consisted of severe reproductive losses, extensive postweaning pneumonia, and suppression of growth. "Mystery swine disease" (MSD) was the name given to the syndrome, and it quickly spread throughout the major swine-producing areas of the United States. By 1990, MSD had occurred in 11 U.S. states, two provinces in Canada, and Germany. During the following year the disease was reported in the Netherlands, Belgium, Spain, and the United Kingdom (Done et al, 1996; Christianson and Joo, 1994; Meredith, 1999). Many etiological agents were proposed as the cause, including encephalomyocarditis virus, *Leptospira interrogans* serovar *bratislava*, PPV, porcine enterovirus, *Chlamydia psittaci*, and mycotoxins. In Quebec, Canada, a new subtype of influenza A virus was isolated from weaned pigs experiencing outbreaks of severe respiratory disease and was considered a potential etiological agent. Despite the intensive research efforts, the etiology of the disease complex remained unknown until 1991, when a viral agent was isolated (Wensvoort et al, 1991). It was possible to reproduce both the reproductive and respiratory disease and fulfill Koch's postulates. The virus was called Lelystad virus (LV) (Terpstra et al, 1991). The isolation of the etiological agent led to advances in diagnostic techniques, and soon evidence of the virus was found in Denmark, Malta, Luxembourg, Japan, Korea, Italy, Poland, and Russia. Finally, at the first international symposium held to discuss the latest information about the virus, it was officially designated as PRRSV.

The terms *mystery pig disease* and *blue-eared pig disease* were used because the etiology was unknown and the skin of the ears of affected pigs commonly appeared blue. The disease affected pregnant gilts and sows, unweaned and recently weaned pigs, and growing-finishing pigs. Outbreaks of late-term abortions, high numbers of stillbirths and mummified or weak newborn piglets, and respiratory disease in young unweaned and weaned pigs were common.

Etiology. Since its identification, rapid progress has been made on the characterization of PRRSV (Benfield et al, 1992). The virus was initially isolated on porcine alveolar macrophage cell lines (Wensvoort et al, 1991). It appears to be a positive strand RNA virus classified into the genus Arterivirus. It is spherical, enveloped, and ranges in size from 45 to 80 nm. Because of the presence of an envelope, rapid inactivation of PRRSV is possible following pretreatment with chloroform or ether. Disinfectants such as formaldehyde and phenol-based compounds appear effective at neutralization. The virus is stable under freezing conditions, retaining its infectivity for 4 months and up to 3 years when stored at 270° C. Infectivity is greatly reduced with increasing temperature (15 to 20 months at 220° C, 30 days at 4° C, 6 days at 20° C, and 15 to 20 minutes at 68° C). PRRSV is also sensitive to changes in pH, and infectivity is reduced over 90% at pH levels less than 5 and greater than 7.

The virus does not survive for long periods on fomites (Pirtle and Beran, 1996). Virus was not recovered after periods of exposure greater than 30 minutes to fecal slurry, porcine urine and saliva, plastic, stainless steel, rubber, wood shavings, straw, and alfalfa. Despite limited viability, the virus was recovered for up to 9 days from well water and up to 11 days for city water.

There are antigenic differences between strains of the virus. The amino acid sequences of open reading frames (ORFs) 2 to 7 of North American strains share only 55% to 79% homology with European strains, whereas those of Canadian and U.S. origin have greater than 90% homology (Benfield et al, 1992). Variation has also been reported between U.S. isolates. Analysis with PCR and molecular sequencing found up to 15% heterology between ORFs from U.S. isolates, with ORF 5 being the least conserved.

Epidemiology. The literature on the epidemiology of the disease has been reviewed (Albina, 1997; Zimmerman et al, 1997).

Occurrence. PRRS affects pregnant gilts and sows, unweaned and recently weaned pigs, and growing-finishing pigs. Outbreaks of late-term abortions, high numbers of stillbirths and mummified or weak newborn piglets, and respiratory disease in young unweaned and weaned pigs are common.

Prevalence of Infection. In endemic herds, 30% to 70% of pigs may be seropositive to the virus and about 60% of herds have some seropositive pigs. Although the seroprevalence may be high in herds in some regions, the incidence of clinical disease is lower and variable. Although the number of herds with the acute form of the disease has been decreasing, the infection may be endemic in many herds, characterized by increased mortality and suboptimum performance in nursery pigs, with active spreading of the virus mainly in nurseries. In endemically infected herds, subpopulations of infected animals may exist, consisting of a low prevalence (<10%) of seropositive animals in the breeding animals

and a high prevalence (>50%) of seropositive nursery piglets. The elimination of these susceptible subpopulations by exposing all members of a population to the virus is used as a control strategy in large herds in which there may be subpopulations of highly susceptible breeding females.

Morbidity and Mortality. The morbidity rate in young pigs may be up to 50%, and mortality in nursery piglets can reach 25%. Death is usually associated with secondary bacterial infections such as *S. choleraesuis, Str. suis, A. pleuropneumoniae,* and *H. parasuis*. Major losses occur in reproductive failure, but data for the magnitude of reproductive losses during an outbreak are not readily available. In general, the reproductive performance of positive herds is significantly lower than negative herds.

Risk Factors. The severity and duration of outbreaks following infection are variable. Some herds may be devastated by high production losses, whereas other herds may have almost no losses. Differences in morbidity and mortality may be due to dose of virus at exposure, differences in host susceptibility, differences in strain virulence, environmental or housing differences, or the production practices in the herd.

ANIMAL RISK FACTORS. Nursing piglets lacking maternal immunity, and young growing and finishing pigs and sows lacking acquired immunity from natural infection or vaccination are highly susceptible to infection and clinical disease. Severe disease appears to be more likely in large herds that have a large turnover of pigs and purchase replacements from other herds and do not use a quarantine system. Introduction of the virus to previously virus-naive herds may cause severe economic losses.

IMMUNE MECHANISMS. After natural infection most pigs are resistant to subsequent infection. Circulating antibodies to the virus are detectable within 14 to 21 days after infection based on indirect immunofluorescence test or ELISA (Albina et al, 1994), and 15kD protein is the most immunogenic of the viral proteins and may provide the antigenic basis for the development of improved diagnostic tests. Several structural and functionally distinct and specific antibodies to the virus are generated after infection or vaccination. Cell-mediated immune responses specific to the virus also occur (Molitor et al, 1997). The relative role of humoral and cell-mediated immunity in providing protection against disease is unknown.

A unique feature of infection is that viremia and circulating antibodies may exist together; the antibodies protect pigs from reinfection and reduce or eliminate shedding of the virus in the semen of boars. Sows are immune to further disease caused by the virus following recovery from acute infection. Following an outbreak of reproductive disease the level of performance will return to normal, suggesting that immunity develops following natural exposure. Protection against subsequent reproductive losses is of long duration in individual animals. However, cross-protection to different strains may not occur. Experimentally infected sows are protected against reproductive losses when challenged with homologous virus more than 300 days after initial exposure (Zimmerman et al, 1997). Extended studies against homologous infection found that the duration of protection was at least 604 days which is essentially life long protection (Lager et al, 1997a,b). Protective immunity was based on two criteria: the absence of transplacental transfer of challenge virus, and the apparent lack of virus replication in the dam 21 days after inoculation.

Piglets born from seropositive sows acquire *colostral antibodies,* which decline at highly variable rates from 3 to 8 weeks after birth (Houben et al, 1995). Passive immunity provides effective immunity for the piglets (Chung et al, 1997). However, loss of passive immunity at various ages results in susceptible pigs and infection, which results in persistence of the virus in pigs 6 to 9 weeks of age, these pigs are considered the major reservoir of the virus in farrow-finish herds. In the absence of natural infection, maternal antibodies become undetectable between 6 and 10 weeks of age (Houben et al, 1995). Some litters do not have maternal antibodies and may not have detectable antibodies until 4 weeks of age, and clinical disease may occur at 2 weeks of age (Albina et al, 1994). By 8 weeks of age, antibodies are usually detectable in all pigs and they persist for several months. However, there may be a large variation in the levels of antibodies in piglets at 10 to 12 weeks of age when they are moved to the finishing units (Houben et al, 1995). In longitudinal surveys the seroprevalence of the virus in the 4- to 5-week-old pigs was higher than in the 8- to 9-week-old pigs, and most pigs were negative when they entered the finishing units (Nodelijk et al, 1997). In herds in which the virus persists, sows do not suffer repeated reproductive losses, indicating that some form of protective immunity develops.

The virus has a predilection for immune cells, and disease manifestations can be linked directly to changes in the immune system (Molitor et al, 1997). The replication of the virus in the cells of the immune lineage, especially macrophages, may lead to immunosuppression and may predispose to secondary infections. Thus immunity to the virus may be a double-edged sword; the virus attacks the immune system, which may cause immunosuppression while inducing protective antibodies.

Antibody-dependent enhancement of infection may also occur because low levels of antibody enhance the ability of the virus to enter the pulmonary alveolar macrophage cells and replicate and destroy the cells. This may be important in sucking and nursery pigs exposed to the virus during a period of declining maternal antibody.

ENVIRONMENTAL AND MANAGEMENT RISK FACTORS. Housing of all age groups in one building, introduction of new animals, housing on slatted floors, storage of slurry under floors, exposure to transport vehicles and lack of disinfection procedures have been suggested as factors that increase the probability of herd infection. Lack of quarantine facilities for recently imported pigs is a major risk factor.

PATHOGEN RISK FACTORS. PPRS virus strains have many identical properties but some antigenic differences. Strains of the virus from the United States and Canada are antigenically similar and different from the European Lelystad virus isolate (Mardassi et al, 1994) There are serological differences between the European and American strains, and the antigenic and genomic differences between the North American and European isolates suggest the existence of two genotypes (Rossow, 1998). There are different genotypes and at least three minor genotypes within the major U.S. genotype. Genetic variations exist not only between European and U.S. strains but among the U.S. isolates, indicating the heterogeneous nature of the virus (Nelsen et al, 1999). Antigenic variation may affect the accuracy of diagnostic tests and the efficacy of vaccines.

Infection with the virus does not always lead to clinical disease, and the detection of high levels of serum antibody in many herds without history of clinical disease suggests that the consequences of natural and experimental infection depend on a complex of factors associated with host susceptibility and virus virulence (Rossow, 1998). The effects of the virus on reproductive performance are strain dependent. Strains of the virus cross the placenta when given to pregnant sows, and most sows will remain clinically normal and farrow normally. However, depending on the strain used, the number of late-term dead fetuses from gilts infected experimentally at 90 days' gestation may vary widely, and all gilts become viremic and develop antibody. There are also marked differences in pathogenicity for the respiratory tract between American strains of the virus compared with the Lelystad

virus when inoculated experimentally into caesarean-derived, colostrum-deprived, 4-week-old pigs (Halbur et al, 1995). Some strains cause severe lesions of the lymphoid and respiratory systems, which appear to be the major site of viral replication (Rossow, 1998). The difference in pathogenicity may explain the variation in severity of clinical disease observed in field outbreaks.

Field observations have suggested that the presence of the virus in a herd may increase the susceptibility of animals to other infections. However, studies with sequential infection of the virus followed by experimental inoculation with *H. parasuis, P. multocida,* or *A. pleuropneumoniae* have failed to demonstrate increased severity of disease (Solano et al, 1997). Similarly, infection with the virus did not increase the severity of experimental *M. hyopneumoniae* infection in young piglets. Based on diagnostic submissions, however, concurrent pulmonary bacterial infections may occur in up to 58% of cases in which the virus was also isolated (Zeman, 1996).

Methods of Transmission. The virus spreads rapidly within herds when infected pigs are housed in confinement. Up to 90% of sows may seroconvert within 3 months of the virus' being introduced into a closed breeding herd. The mode of spread is presumed to be by direct contact. The virus is present in nasal discharge, urine, and feces, and intranasal inoculation has been used to reproduce the disease experimentally. The virus is present in saliva and, considered in the context of the social behavior of pigs, may play an important role in transmission (Wills et al, 1995; Christopher-Hennings et al, 1995). Positive viral isolation has been made from tonsillar scrapings for up to 157 days after infection (Wills et al, 1997). Although these latter studies have not examined the ability of carrier pigs to shed virus under conditions of stress, one report has demonstrated recrudescence of viral shedding from offspring born of a dam that had been infected at Day 90 of gestation (Albina et al, 1994). Infected offspring remained seropositive for up to 15 weeks of life. At Week 22, 5 mg/kg of prednisolone acetate was administered to seropositive pigs for 5 consecutive days. Seronegative sentinels had been placed within fenceline contact for 9 weeks after initial exposure. All sentinels became infected within 2 to 5 weeks after treatment commenced.

The virus may persist in and circulate among different age groups and locations in a herd for several months despite the absence of clinical disease and may be transmitted by contact to replacement animals or to uninfected farms. Infected pigs may remain carriers of the virus for up to 15 weeks (Albina et al, 1994). Persistent and contact infection can be maintained in a nursery if uninfected pigs are continuously exposed to infected pigs. Pigs in the nursery become infected through contact with older infected pigs and not by *in utero* or postpartum exposure to infected sows (Stevenson et al, 1994). Long-term surveys of farrow-finish herds reveal that isolation rates of the virus reach their highest level of 70% to 100% of pigs 6 to 8 weeks of age, which coincided with the lowest level of maternal immunity (Chung et al, 1997). Large finishing enterprises, purchasing pigs of variable infection and immune status, provide ideal conditions for persistent virus circulation. Breeding herd subpopulations of infected pigs may exist and perpetuate and enhance the infection in a herd; the inability to control such subpopulations may reduce opportunities for successfully controlling the disease.

Infection may persist for an extended period of time because of the following: incomplete infection of the susceptible population during the acute phase; introduction of susceptible breeding stock; persistent viral infection in individual pigs with the potential of shedding virus under certain conditions, such as grouping for weaning or farrowing; rapid decline in passive immunity in young pigs; and variable periods of active immunity. Spread between herds is associated with the introduction of infected carrier pigs.

Infected boars may shed the virus in their semen for up to 40 days after experimental infection. After experimental infection of sexually mature boars, the virus was present in the semen 3 to 5 days after infection, and on days 13, 25, 27, and 43 (Swenson et al, 1994). A PCR assay can detect the virus in semen for up to 92 days after experimental infection. The insemination of gilts with semen from experimentally infected boars resulted in clinical signs of disease and failure to conceive. The use of the modified-live PRRSV vaccine in boars is controversial, because some boars may still shed wild-type virus in semen after challenge exposure 50 days after vaccination.

Exposure of pregnant gilts to either attenuated (vaccine) or virulent (field) strains of the virus can cause congenital infection (Mengeling et al, 1998). Vaccine and field strains can be transmitted postnatally from infected to noninfected littermates. Pigs infected with field strains have an inferior rate of survival and growth than do noninfected pigs. This suggests that use of attenuated virus vaccine during gestation is questionable. Attenuated PRRSV vaccines may have to be administered to naive gilts more than 30 days before conception to provide maximum protection throughout gestation (Mengeling et al, 1999).

The disease has occurred in PRRSV-seropositive herds in Denmark with no previous clinical evidence of PRRSV disease that were then vaccinated with a modified-live-virus vaccine licensed for use in pigs 3 to 18 weeks of age (Botner, 1997). Boars entering AI units were also vaccinated. After vaccination, a large number of herds experienced an increased number of abortions and stillborn piglets and an increasing mortality in the nursing period. The problems occurred mainly in herds without clinical signs among sows and with sows with low antibody titers in the period immediately before vaccination. The PRRSV was isolated from fetuses and identified as the vaccine virus. The evidence suggested that the vaccine virus had spread to nonvaccinated sows, followed by transplacental infection of the fetuses. Spread of the vaccine virus was also demonstrated in a nonvaccinated and previously virus-free breeding herd. Possible routes of transmission include introduction of vaccinated animals, use of semen from vaccinated AI boars, and aerosol transmission.

Airborne spread across regions and between countries is suspected. In Europe, during the winter of 1990 to 1991, the infection appeared to spread by the airborne route from Germany, across the Netherlands and into Belgium. Low temperatures, low sunlight, and high humidity may have facilitated airborne spread. Whereas aerosol transmission was once felt to be a definite method of transmission, the status of the potential for transmission of virus through aerosols is under debate (Torremorell et al, 1997). Initial observations from numerous European countries consider airborne spread a highly likely possibility, primarily if specific weather conditions such as high humidity, low temperatures, and low wind speeds exist. Transmission through aerosols may also be more likely if the surrounding area is densely populated with naive swine. Finally, although PRRSV appears to be closely related to lactate dehydrogenase elevating virus of mice, the ability of rodents to spread PRRSV has not been demonstrated under controlled conditions (Hooper et al, 1994). Airborne spread up to 20 km has been suggested, but most airborne spread is probably limited to less than 2 km.

Epidemiological investigations in Belgium attribute 70% of herd infections to local spread, 9% to purchase of infected pigs, 4% to other contacts, and in 18% of cases the source of infection could not be determined. There is no ev-

idence that rodents are susceptible to infection with the virus and are probably not a reservoir for the virus (Hooper et al, 1994).

Most spread between herds occurs by the introduction of unknown infected breeding stock into herds previously uninfected. Primary infections are common in multiplying herds that supply unknown infected replacement gilts to other farms.

The PRRSV is labile and does not survive for more than 1 day on solid fomites but for several days in well and city water (Pirtle and Beran, 1996). It may survive for several years in deep frozen tissues but for only 1 month at 4° C, 48 hr at 37° C, and less than 45 min at 56° C.

Pig meat does not retain detectable amounts of the virus, and it is unlikely that transmission through meat occurs.

Economic Importance. The export market for pork from a country can be seriously affected when a disease such as PRRS occurs. When the disease was recognized in the United States, countries such as Mexico, Japan, Canada, and South Korea banned the importation of pork from the United States or required certification that the swine originated from premises in which, within the 30 days before the issuance of the health certificate, no swine were introduced from a municipality in which a premises infected with the virus was located.

The economic losses may be high because of stillbirths, abortions, small litter sizes, birth of weak pigs (which increases preweaning mortality), and increased nonproductive days. In weaned pigs losses are associated with respiratory disease. In addition, there are the costs of control that may be high depending on the control strategies undertaken. Typically, about 20% loss in annual production can be expected from a severe outbreak.

Pathogenesis. Initially a viremia occurs with subsequent distribution and multiplication of the virus in multiple body systems and organs causing interstitial pneumonia, vasculitis, lymphadenopathy, myocarditis, and encephalitis (Rossow et al, 1995). The viremic period exists in the adult animal for 14 days, providing adequate time for transplacental transmission (Terpstra et al, 1991). Alveolar macrophages are primary targets for virus multiplication, but this does not fully explain the pathogenesis (Molitor et al, 1997). The effects of the virus on the immune system may explain the suspected immunosuppression and secondary infections that are recognized clinically but have not been reproduced experimentally.

Vascular lesions associated with PRRSV infection are analogous to those observed in horses with equine arteritis virus, also a member of the Arteriviridae (Cooper et al, 1997), and the renal lesions of equine viral arteritis infection correspond with those of PRRSV. Inflammatory infiltrates are seen at the junction of the renal cortex and medulla, with vascular changes associated with muscular tunics of small arterioles.

The characteristic lesions can be reproduced in conventional pigs at 1, 4, or 10 weeks of age, and the variation in severity of clinical disease can be attributed to differences in strain virulence (Halbur et al, 1995; Rossow et al, 1994). The effects of the virus on reproductive performance are also strain dependent (Mengeling et al, 1996). Some strains are of low pathogenicity, whereas others are highly pathogenic. The reproductive disease has been reproduced experimentally, and the effects on the fetus are dependent on the stage of gestation. Aerosol exposure of nonimmune pregnant gilts in late gestations (84 days) to the Lelystad virus causes clinical disease (Christianson et al, 1992). After an incubation period of 4 to 7 days, all sows were inappetent and listless for 6 to 9 days. Some sows develop blue ears, accompanied by abdominal respirations. Sows may farrow at Days 116 and 117 of gestation, giving birth to dead, mummified, and live piglets. Many of the live-born piglets are pale, listless, and weak, and some are in respiratory distress and exhibit varying degrees of splayleg or muscular tremors. The virus may be isolated from stillborn piglets or those born alive. Antibody is present in precolostral serum samples or ascitic fluids of piglets, which demonstrates transplacental passage of the virus.

The pathogenesis of PRRSV infection in the weaned pig has been studied extensively. Up to 40% of the mature populations of alveolar macrophages is destroyed by 7 days after infection, and the residual populations have reduced function (Pol et al, 1991). The release of interleukins from damaged cells causes inflammatory changes. As previously described, alveolar septae are infiltrated with macrophages, and cellular debris fill alveolar spaces. The severity of the clinical signs following infection appears to be highly correlated to the existing health status of the herd. Field observations indicate that PRRSV appears to predispose the respiratory system to coinfection with opportunistic bacterial agents (Galina, 1995). As previously described, it is common to isolate a myriad of bacterial pathogens from cases of respiratory disease, such as *H. parasuis, S. choleraesuis,* and *A. pleuropneumoniae.*

While PRRSV also predisposes pigs to *Str. suis* meningitis, it has been difficult to reproduce other relationships between PRRSV and other bacterial pathogens of the respiratory tract, under controlled conditions.

Clinical Findings. The severity of the clinical findings in acutely affected pigs can be extensive throughout the herd. All stages of the disease may occur on an infected farm, including abortions in the breeding herd and influenza-like signs in the finishing pigs. The following section reviews the clinical findings of PRRS infection in the different stages of production (Zimmerman et al, 1997; Done et al, 1996).

Breeding/Gestation. In adult animals there may be anorexia, lethargy, and depression. Pyrexia may be present (40° to 41° C), and sows may abort most commonly during the last trimester of gestation. The rate of abortion may exceed 10% during outbreaks of the acute form. Premature farrowings usually occur around 105 to 107 days of gestation. Clinical signs may appear in different groups of breeding animals each week, in contrast to infection with TGE virus or pseudorabies virus, in which large numbers of animals are anorexic at one time. This "rolling anorexia" may persist in a group of sows for up to 4 to 7 days. Farrowing rates may decrease from 20% to 40%. Occasionally, sows may vomit and lie in lateral recumbency. The mortality rate of sows may increase 3% to 5% during the acute infection, particularly in periparturient animals. There is usually an increase in repeat breeders, NIP sows and an inability to achieve the desired numbers of matings per female. A chronic form of PRRS can exist in the breeding herd. Typically, when nonimmune gilt replacements are introduced into an infected herd, there is an increase in stillbirths and an increase in preweaning mortality and conception failure. Although not as extreme as the acute outbreak, the problem may persist over a 1- to 2-year period (Dee and Joo, 1994b).

Farrowing. In farrowing sows there is a marked increase in the rate of stillbirths and mummified pigs. Stillbirth rates may increase up to 50% to 75%. The fetuses are brown, macerated, and appear to have died 5 to 7 days before parturition. Chronologically, a rise in stillbirths is preceded by an increase in abortions or early farrowings. Following the rise in stillbirths, a 20% to 30% increase in the rate of mummified fetuses may occur. Preweaning mortality levels can reach up to 60% to 80% within a farrowing group. Suckling piglets demonstrate "thumping," a unique pattern of rapid abdominal breathing with an open mouth. Sows

will usually be lethargic and agalactic, causing a high incidence of colostrum deprivation in piglets and a subsequent increase in the incidence of neonatal colibacillosis in the piglets throughout the farrowing groups.

POSTWEANING. Although the acute reproductive outbreak may be remarkable, it is usually of short duration (3 to 4 months). In contrast, postweaning abnormalities may persist for up to 1 to 2 years and cause significant economic loss. Average daily gain in the nursery pigs may be reduced up to 50% to 75%, and mortality levels frequently rise to 10% to 25%. The primary clinical entity in nursery piglets or growing-finishing pigs is an increased level of pneumonia, causing acute death loss or chronically slow growth. There may also be a sudden increase in the incidence of AR or postweaning colibacillosis. Samples submitted for laboratory diagnosis usually yield numerous bacterial and viral pathogens. Common isolates include the PRRSV, swine influenza virus, porcine respiratory coronavirus, *M. hyopneumoniae, P. multocida, Str. suis, H. parasuis, A. pleuropneumoniae,* and *S. choleraesuis*. The affected animals respond poorly to medication, causing a high level of frustration among producers and practitioners.

Because of the prevalence of other pathogens associated with the virus infection, gross lesions of PRRS may be obscured. In uncomplicated infection the gross appearance of the lung is one of a "fish flesh" consistency.

Necropsy Findings. The gross and microscopic lesions in the fetuses from sows experimentally infected oronasally with the virus at 90 days of gestation consist of hemorrhage of the umbilicus and necrotizing umbilical arteritis with periarterial hemorrhage (Lager and Halbur, 1996). Severe pulmonary lesions are present in fetuses inoculated in utero with the virus between 45 and 49 days of gestation. When sows are inoculated oronasally with the virus in midgestation, the virus does not readily cross the placenta but replicates in fetuses that are inoculated directly in midgestation. Thus the fetuses are more susceptible in late gestation than earlier in midgestation, or there is greater likelihood of transplacental infection during late gestation. Experimentally, the intrauterine inoculation of the virus into gilts on the day after natural breeding may have little or no effect on their reproductive performance.

In pigs that have died with respiratory disease, the lungs are heavy and consolidated. Histologically, there is a necrotizing interstitial pneumonia characterized by thickened alveolar septae, resulting from macrophage infiltration (Pol et al, 1991). Alveolar spaces also contain proteinaceous debris and degenerating cells in all lobes. In contrast to swine influenza virus infection or proliferative and necrotizing pneumonia, there is no involvement of the airways with PRRSV infection. Other lesions detected through microscopic examination include lymphoplasmacytic rhinitis, perivascular cuffing with mononuclear cells in the brain, mononuclear myocarditis, splenitis, and depletion of the thymic cortex, tonsilar crypts, and lymph nodes.

Diagnosis. The most important component of the control program is the proper use of diagnostic tests, to accurately determine the point of infection within the life of the pig (Mengeling et al, 1995; Botner, 1997). This information enhances the decision-making process regarding selection of the control strategy. New techniques, such as PCR have enhanced detection of viral antigen (Suarez et al, 1994). Samples suitable for analysis by PCR include serum, semen, and tissue. Positive PCR signals can be sequenced and samples of field virus can be differentiated from modified-live virus vaccine isolates. The use of PCR is valuable, particularly when investigating PRRS problems in lactation or nursery. This test is much more sensitive than virus isolation, and results are available in a shorter period (24 to 48 hours). Recent data have shown that shedding of PRRSV can be limited to gilt litters during lactation, and that shedding can occur at any time during the suckling period, resulting in infected piglets at 1 to 2 days of age (Dee and Philips, 1999). An example of a protocol to detect transmission of field-virus from sows to pigs during the lactation period is as follows:

- Collect sera from 5- to 7-day-old piglets, collecting 1 to 2 piglets/litter
- Sample across parities (6 piglets/parity)
- Pool sera 3:1 within each parity
- Example: Six parities are in lactation on a given sampling day

6 Parities × 6 Piglets sampled/Parity = 36 Samples

Samples pooled 3:1 = 12 Samples submitted

If virus shedding is occurring during lactation, the 5- to 7-day-old piglet has been shown to be a sensitive sample for the detection of PRRSV before weaning. During the sampling process, samples should be kept cool at all times and should be shipped to the diagnostic laboratory over night on ice. It is better to refrigerate samples than to freeze them. Serologic assays, such as the ELISA, are used for the detection of antibodies after exposure to virus. The IDEXX ELISA reports result in the form of a sample-to-positive (s/p) ratio, and s/p ratios of 0.4 or higher are considered positive. However, these data are only indicative of exposure to virus, not of protection. Cross-sectional sampling by stage of production can be useful to determine the point of infection in the life of the pig. Samples should be collected from the breeding herd across all parities, recently weaned pigs, 8- to 10-week-old nursery pigs, and 5- to 6-month-old finishing pigs. Testing by parity may indicate whether programs need to focus on a specific subpopulation within the herd, such as gilts. Unfortunately, diagnostic tests that differentiate antibodies because of natural infection from those induced following vaccination are not available at this time. Furthermore, it is also important to realize that PRRSV infection, without the presence of opportunistic pathogens such as *M. hyopneumoniae* or *Str. suis,* may have little impact on the health and performance of pigs. Therefore it is important to use clinical observations and production records in conjunction with diagnostic data to properly understand the status of the sampled population. Once the pattern of virus spread and the age in which the pig is infected is determined, intervention strategies can be initiated.

Treatment

ACUTELY INFECTED HERDS. Establishment of a cost-effective treatment program following an acute PRRS outbreak in a previously nonimmune herd is often futile and frustrating. The following section summarizes practical intervention strategies that have been reasonably successful.

- *Breeding/Gestation*: Because of the reproductive effects of PRRS on sows, pregnancy loss and conception failure are high. Therefore, in order to ensure adequate numbers of farrowings, overbreeding is recommended. Because boar libido may be reduced in some cases, AI should be used to ensure adequate numbers of viable sperm cells. Clinically affected animals with a fever may be treated with parenteral antibiotics. Antiinflammatory drugs such as fluxinin meglumine are sometimes used to reduce pyrexia and inflammation. Antibiotics in the feed such as tetracycline at 400 to 800 g/ton can be used to control secondary bacterial agents.
- *Lactation*: Similar to gestating animals, broad-spectrum antibiotics, and antiinflammatory products are indicated. Because of reduced feed intake, diets may be reformulated to contain higher levels of nutrients.
- *Suckling Pigs*: Castration or weaning should be delayed as long as possible. Needles used for injections should be

dipped in iodine between pigs following injections to avoid hematogenous viral spread. Cross-fostering pigs should be limited to the first 2 days of life. Following this period, litters should remain intact. The use of nurse sows should be avoided. Farrowing environments should be maintained at 28° to 30° C to keep pigs warm. Similar to a TGE outbreak, if preweaning mortality of the affected farrowing group is particularly high (>75%), it may be more advantageous to humanely destroy chronically infected survivors, or to transfer the entire group to a different weaning site in order to prevent these chronically infected pigs from entering the nursery and exacerbating the problem in this area. If an interruption in pig flow can be created between farrowing and nursery groups, pig-to-pig transmission may be minimized. Lactating sows should be treated with antibiotics, appetite stimulants, and antiinflammatories. Electrolyte solutions with vitamins should be provided to both sows and pigs.

- *Postweaning*: Besides parenteral antibiotic therapy, all-in, all-out pig flow is important. Thorough washing of the facility using water temperatures of 90° to 94° C along with disinfectants effective against PRRSV is recommended. Products such as formaldehyde-based disinfectants, or phenol-based compounds have proved effective against the virus. Autogenous bacterins for specific pathogens have also been used, as have oral or injectable immune stimulants (vitamin E/selenium), but results have been mixed.

Control. Following cessation of the acute infection, a control program must be recommended and implemented. The following section summarizes the major control strategies practiced in the industry today.

VACCINATION. Because of the necessity of cell-mediated immunity to control PRRS, modified-live virus vaccines appear to be more efficacious than killed preparations (Molitor et al, 1997). Although MLV products do shed in naïve populations, transmission has not been detected following revaccination (Dee and Philips, 1999). Diagnostic profiling is especially critical when vaccination is used to avoid immunizing pigs concurrently infected with field virus. It is important to develop farm-specific vaccination programs, based on individual farm diagnostic data, rather than to promote standardized protocols. Proper handling of modified-live virus vaccines is important to enhance efficacy. An adequate needle length ensures that intramuscular penetration is obtained. A 3.81-cm needle is required for adult breeding animals, whereas 2.54 cm is required for finishing pigs and 1.27 cm for weaners. The product must be rehydrated using the proper diluent and administered within 24 hours after hydration. Finally, use of a designated syringe, rinsed with only hot water and not disinfectant, is important as well.

GILT DEVELOPMENT. Gilt development is a very important component of a control program. Direct introduction of naïve or actively infected replacement stock enhances viral shedding and exacerbates PRRS problems (Dee and Joo, 1994a,b). Therefore it is critical to establish a gilt development program, consisting of quarantine and an acclimatization period, to properly develop replacement stock before entry to the herd (Dee, 1997). Changes in gilt development strategies in the United States include introducing gilts as weaners or 25-kg piglets, housing them in designated developer facilities, and establishing vaccination and acclimation protocols in an attempt to equalize the health level of this population to the existing breeding herd. Despite the use of cull sows or infected nursery pigs as sources of farm-specific viral strains, consistent induction of natural exposure can be frustrating, particularly in chronically infected herds, because of lack of active circulation of field virus. Therefore it is important to maintain the use of vaccination in gilt developer protocols to reduce the risk of developing naïve subpopulations. The purchase of gilts from PRRSV-negative sources enhances the importance of proper natural exposure to farm-specific strains before herd entry. If PRRSV-positive sources are employed, it is important to ensure that a change in source does not occur and that actively infected animals do not directly enter the recipient herd. For this reason, quarantine periods of 60 days or more are used, and quarantine facilities function on an AIAO basis.

NURSERY DEPOPULATION. ND is a cost-effective means to interrupt horizontal transmission of PRRSV from older, infected pigs to those recently weaned. Significant improvements in nursery pig daily gain, mortality, treatment cost, and profitability have been published, following implementation of ND (Dee et al, 1997a,b). Despite such improvement, reinfection of nurseries with PRRSV is a frequent event, often taking place 12 to 18 months after completion of the depopulation protocol. Therefore it has been speculated that the primary benefit of this strategy may be for the control of opportunistic pathogens, rather than PRRSV. ND consists of emptying, washing, and disinfecting all nursery rooms and allowing the facility to remain empty for a minimum of 2 days. Because of the poor viability of PRRSV outside of the pig, extended periods of downtime can be avoided, enhancing facility use and eliminating the virus from the nursery pig population (Pirtle and Beran, 1996). Disinfectants frequently recommended include phenol- or formaldehyde-based products to reduce survivability of the virus in the environment (Benfield et al, 1992). This strategy can also be applied to PRRSV-infected finishing populations.

ERADICATION. Eradication of PRRS is currently being evaluated (Dee and Molitor, 1998; Dee et al, 2000). Because of the ability of PRRSV to induce transplacental infection, or to be shed during lactation through saliva, milk, or colostrum, consistent production of noninfected piglets using segregated production and early weaning is not possible in the long term. The process of T&R may be an efficacious strategy and is currently under investigation. T&R has been used successfully to eliminate Aujeszky's disease virus and *A. pleuropneumoniae*. The primary focus of this strategy is to test all breeding animals, identify carriers, remove them from the herd, and prevent vertical transmission of PRRSV (Dee, 2000). Analysis of sera using ELISA for the detection of antibodies along with PCR for the detection of viral protein is used in combination to identify previously exposed, potentially infected animals. The detection of carriers is critical because of the ability of PRRSV to produce persistent infection (Wills et al, 1997). Although PRRSV persistence is not lifelong, infected sows pose the greatest risk for perpetuating virus transmission within an infected farm.

Eradication strategies using T&R have been applied to some farms in the United States with promising results (Dee and Molitor, 1998, Dee et al, 2000). These farms were originally infected with PRRSV 1 to 2 years before initiation of T&R. Before the initiation of T&R, ELISA seroprevalence of the breeding herd ranged from 6% to 12%. Herd size ranged from 200 to 1500 sows, and not all farms had employed PRRSV vaccination at any time after the initial outbreak. At this time, all farms have been declared PRRSV negative after completion of the protocol and a 12- to 24-month monitoring program. Carrier sows have been identified primarily as being parity 2 or older (6+ parities). Removed animals have tended to cluster in small groups or reside as single entities randomly located throughout the gestating population, but ELISA data from sow clusters appear to be distributed normally (Dee, 2000). This suggests that virus transmission in chronically infected farms occurs over short distances and

may be of low magnitude. In conclusion, although such strategies still require further testing, the PRRSV knowledge base continues to grow and expand, leading to a higher degree of successful control throughout the world. Eradication of the disease has been achieved in some Danish swine herds through the use of both total and partial depopulation (PD) (Andreasen et al, 1998).

Porcine Parvovirus. PPV causes reproductive failure, characterized by embryonic and fetal death, when susceptible sows and gilts are exposed to the virus during the first 56 to 70 days of gestation. Epidemics of PPV usually are characterized by an increased frequency of mummified fetuses and reduced litter size, but decreased conception and an increased frequency of stillborn or weak newborn piglets also occur. PPV infection is ubiquitous and enzootic in most swine herds.

The primary means of PPV infection is through the oral route. The virus can be transmitted by salivary or nasal secretions of infected pigs as well as through the feces. PPV is extremely thermostable and resistant to many common disinfectants, thus it is capable of surviving under farm conditions for long periods.

The major and usually only clinical response to PPV infection is reproductive failure. PPV is capable of crossing the placenta, and the damage caused by the disease depends primarily on the stage of gestation (in days) of the pig when infection occurs.

Conceptuses infected before 56 days undergo a wide spectrum of microscopic changes. Embryos die and are resorbed. The gilt may then return to estrus at the regular interval or experience a delayed return. Fetuses show stunted growth, increased prominence of blood vessels on the surface of the skin, edema hemorrhage, discoloration, and dehydration (mummification). In contrast, the litters of pregnant females infected after 56 days' gestation usually remain alive and show none of these signs. This is because transplacental crossing of PPV takes approximately 10 to 14 days, thereby infecting fetuses around 70 days. It has been established that at this period of gestation, porcine fetuses are capable of establishing immunocompetency and can survive the viral infection by using their own defense mechanism. The most efficient method of diagnosis of fetal infection is serology on fetal body cavity fluids by immunofluorescence (Waldvogel et al, 1995). Paired acute and convalescent gilt sera, if available, should be tested for PPV antibody.

Before development of commercial vaccines, control of PPV-induced reproductive failure was based on exposing replacement females to PPV by placing them in pens that might be contaminated with the virus, placing them in contact with older sows that might be infected, and feeding them feces or tissues from mummified fetuses. These procedures induced variable immunity because PPV was not always in the feces, tissues, or environment. When effective exposure to the virus was achieved, however, immunity probably persisted for the lifetime of the pig (Gardner et al, 1996).

Natural infection with PPV confers more effective immunity than vaccination and may be the preferred method of control. In many herds, however, females are not consistently exposed to virus before their first breeding, and veterinarians and producers must balance the costs of vaccination programs against the likely risks of reproductive failure when females are not vaccinated. For most herds in the United States, serologic screening for PPV before selection of a vaccination program is unlikely to be cost-effective, because vaccination is relatively inexpensive (Gardner et al, 1996).

Pseudorabies. Pseudorabies, or Aujeszky's disease, is caused by the pseudorabies virus or suid herpes virus 1 of the family Herpesviridae. The disease is widespread in pigs and causes heavy economic losses to swine industry worldwide (Miller et al, 1995). Pigs are the sole reservoir of infection and the only source of virus transmission and direct oronasal contact between infected and susceptible pigs is the primary method of transmission. The virus is widely present in feral swine, which do not exhibit any clinical abnormalities (Hahn et al, 1997; Romero et al, 1997). This seriously affects efforts to eradicate the virus from the domestic swine population. Aerosol spread between farms in an area is also considered possible. Substantial losses occur because of reproductive failure resulting from abortions, stillbirths, and mummification in sows; mortality of young pigs; and respiratory disease in older pigs. PRV infection in susceptible gilts produces mummified fetuses with average live litter sizes of 1.9 pigs. Sows may also delay farrowing up to 2 to 3 weeks and may suffer from impaired fertility and low conception rate in future breeding attempts.

Latent infection occurs in surviving pigs, and intermittent reactivation of the latent virus can result in excretion and spread to other susceptible pigs. The virus is primarily introduced into a herd through the inadvertent addition of infected carriers. Large herd size and frequent mixing of pigs increase the probability of exposure to an infected animal. Farrow-to-finish operations allow prolonged contact with infected animals. Indoor confinement increases population density and provides a contained environment for circulation of the virus in aerosols.

In most countries, vaccination is used to reduce clinical losses. In areas with a high prevalence of infection, vaccination is widely used to protect pigs against clinical disease. It can also limit the spread of virulent virus between animals or herds by decreasing the level of their excretion from vaccinated pigs. The control of pseudorabies is difficult and currently unreliable, because normal healthy pigs may be infected and shed the virus for up to several months.

The methods of control or eradication include *depopulation and repopulation, test and removal, segregation of progeny,* and *vaccination*. The selection of a strategy for the control or elimination of the disease depends on the source of the herd infection, the method of transmission of the virus, the survival of the virus in the environment, the sensitivity and specificity of the diagnostic test and the risk factors in the herd. The risk factors of the herd include the type of operation, the degree of herd isolation, the prevalence of infection, the value of the genetic material, the level of management expertise, and the availability of suitable virus-free replacement swine if depopulation and repopulation is chosen as a strategy (Siegel et al, 1999). Breeding stock producers favor eradication; farrow-finish producers who do not sell breeding stock or feeder pigs are generally more concerned with the reduction of losses from clinical pseudorabies infection than with eradication.

Depopulation-repopulation is the most expensive, segregation of progeny method the next least, and the T&R the most inexpensive per sow. The optimum alternative is to test and remove seropositive animals if the initial prevalence is <57%; otherwise vaccination of sows only is preferred. Vaccination may be recommended at lower prevalence rates as a conservative approach. Eradication by T&R combined with the use of gene-deleted vaccines is advantageous at any prevalence rate of infection. Depopulation and repopulation is not the best option under any circumstances.

In the United States the national pseudorabies eradication program was implemented in 1989 as a joint state-federal-industry sponsored program.

An epidemiological model projected future herd-herd disease transmission under alternative eradication or control programs over 20 years, from 1993 to 2012. With current eradication program funding in the United States, the

prevalence of infection would be 23% in high-risk states, 10% in moderate-risk states, and 1% in low-risk states. Increased funding for the eradication program would reduce the prevalence of infection substantially. Profitability for the average size farrow-finish herd was estimated to be $6/cwt of swine produced for virus-infected herds than for uninfected herds (Miller et al, 1995). Estimates of the value of economic welfare indicated that consumers would be the major beneficiaries of eradication because of reduced prices and increased consumption of pork (Miller et al, 1996). The details of the control programs are available (Radostits et al, 2000). A summary is set out here.

Determination of Prevalence of Infection. In large herds the virus must be eliminated from the growing-finishing pigs and the breeding herd. Large herds that are virus positive are infected in both groups; smaller herds are frequently infected in only the breeding herd. An initial step in eradication is to determine the prevalence of infection. Representative samples of finishing pigs older than 4 months and of breeding sows, gilts, and boars are tested. On the basis of the test results and the risk factors in the herd, a cost-effective plan can be devised for the individual herd.

Depopulation and Repopulation. When the prevalence of infection in the herd is over 50%, eradication can be achieved by depopulation and repopulation with virus-free breeding stock. However, depopulation is the most expensive method and is not compatible with the retention of valuable pedigree stock. The entire herd should be depopulated over a period of months as the animals reach market weight. After removal of the animals the entire premises are cleaned and disinfected. Repopulation should be delayed at least 30 days after the final disinfection, and swine should originate from a pseudorabies-free qualified herd and be isolated on the premises and retested 30 days after introduction. All herd additions should be isolated and tested 30 days after introduction.

Test and Removal. The T&R program is recommended when the prevalence of infection in the herd is below 50%. This method requires testing of the entire breeding herd and immediate removal of all seropositive animals; 30 days after removal of seropositive animals, the herd is retested (if necessary, at 30-day intervals) until all herd tests are negative. Following a second negative test, the testing regimen may be changed to test only 25% of the herd every 4 months. Seropositive animals are identified and culled. The T&R method is superior to the vaccination system as a method of control. Valuable genetic material may be salvaged from breeding stock that are seropositive through the use of embryo transfer techniques. Embryos may be transferred safely to susceptible recipient gilts from sows that have recovered from infection, but not from sows that are in the active stages of infection. The virus does not penetrate the outer covering of the embryo, but it can become attached to it so that it may physically transfer to the uterus of the recipent. This transfer of infection may occur if the donor sow is in the active phase of infection.

Offspring Segregation. The objective of this strategy is to raise a pseudorabies-negative breeding herd to replace the infected herd. Once the herd is diagnosed as pseudorabies infected, a regular schedule of vaccination is instituted. Gilts are vaccinated at first breeding, and both sows and gilts are vaccinated 2 to 4 weeks before farrowing to provide a high level of colostral immunity to their piglets. Offspring are removed at weaning and raised apart from the infected herd. At 4 months of age, and then again before breeding, the segregated replacements are tested for antibody. Since colostral immunity is no longer detectable by 4 months of age, any animals over 4 months of age that are seropositive are considered pseudorabies infected. As the gilts reach reproductive maturity, the old sow herd is replaced. Segregation between the infected sow herd and the clean gilt herd is maintained until all positive sows have been removed and the facilities disinfected. Groups of seronegative pigs are identified and combined into larger groups to establish a new herd. The original herd is gradually depopulated and the premises cleaned and disinfected. The new herd is then monitored on a regular basis. Herds that are not successful have been slow to adopt new technologies, particularly biosecurity and disease control procedures (Deen et al, 1995a,b).

Control Programs in Effect. A pseudorabies control program was introduced in England in 1983 when the infection was spreading rapidly. New legislation imposed restrictions on the movement of pigs when clinical signs of the disease were present in the herd. The first part of the eradication scheme involved testing all of those herds previously known to have pseudorabies. Within several months after the beginning of the eradication campaign, 417 herds had been slaughtered, involving 342,275 pigs, of which 72.5% were salvaged. Only 121 herds had been known to be previously infected, whereas the remaining 296 herds had been identified through tracebacks and reports of new cases. By 1985 it was concluded that the disease was well controlled in England with only 10 to 14 infected herds remaining. Farmers were compensated for all animals slaughtered and for consequential loss associated with the loss of stock. The cost of the eradication program was financed by a levy on all pigs normally marketed for slaughter in England. In 1995 England was free of Aujeszky's disease. In Northern Ireland pseudorabies is more widespread than it ever was in Britain before the eradication program. Because the infection rate is over 50%, an eradication program based on slaughter of infected herds would destroy the swine industry. Thus the control program in Northern Ireland is based on the use of vaccination, the culling of seropositive animals, and the gradual introduction of seronegative animals.

Pilot projects were conducted in Iowa, Illinois, Pennsylvania, Wisconsin, and North Carolina from 1984 to 1987. In the pilot projects, 97.5% of 116 herds that were initially pseudorabies positive were successfully cleared of infection. This indicated that eradication of pseudorabies virus from herds of swine can be achieved efficiently and is most effective when applied on an area basis. The introduction of the gene-deleted pseudorabies vaccines in the program was the technical breakthrough needed to be able to offer the national eradication program, since it was now possible to distinguish between naturally infected and vaccinated animals. The program consisted of five stages: Stage I: preparation; Stage II: control; Stage III: mandatory herd clean-up; Stage IV: surveillance; Stage V: free.

When an outbreak of the disease occurs in a susceptible herd, the mortality may be very high and the first consideration is to prevent spread to uninfected sows and litters and to pregnant sows from infected pigs. They should be attended by separate personnel, or adequate barriers to mechanical transmission of infection should be arranged. On affected premises cattle should be separated from pigs, and dogs and cats should be kept from the area. The affected herd should be quarantined, and all pigs sold off the farm should be for slaughter only.

Vaccination. Vaccination is used to reduce clinical disease when outbreaks occur or when the disease is endemic in the herd. An effective immunity develops after natural infection or vaccination, and piglets from immune sows are protected from clinical disease during the nursing period by colostral immunity. However, the *presence of circulating antibody does not prevent infection, the development of latency, or subsequent*

activation and excretion of the virus. But vaccination reduces viral shedding after natural infection. On farms in which the disease is endemic or outbreaks have occurred, vaccination of the sows and management procedures to reduce the spread of infection have markedly reduced preweaning mortality and reproductive failures. In field studies of large numbers of herds in which the sows were vaccinated three times annually, the reproduction ratio was below 0.66 (which is significantly below 1) and massive spread of the virus did not occur.

It is often virtually impossible to prevent the spread of infection in a susceptible herd, so vaccination of all pigs at risk, especially pregnant sows, is recommended, The vaccine reduces losses in infected herds, limits the spread of infection, and decreases the incidence in endemic areas. With a properly controlled and monitored vaccination and culling program in a breeding herd, it is possible to control clinical disease and reduce the infection pressure. All breeding stock present during an outbreak are subsequently vaccinated regularly until they are all culled, which removes the major sources of virulent virus. After this phase newly introduced gilts and boars are tested and monitored regularly. This is considered less costly than the test and slaughter policy. Additional details on vaccines and vaccination strategies are available (Radostits et al, 2000).

Hog Cholera Virus. Hog cholera virus is classified in the family Togaviridae, and its natural host is the pig. It can be transmitted through infected feces, nasal secretions, infected fomites (e.g., vehicles, boots, and garbage containing contaminated pork scraps). The virus is capable of crossing the placenta of pregnant sows, causing stillbirths, mummified fetuses, and small litters of weak "shaker" pigs. Hog cholera was eradicated from the United States in 1978. Outbreaks occur sporadically in other parts of the world (see earlier in this chapter).

Swine Influenza Virus (SIV). Swine influenza is a common and seasonal respiratory disease caused by Type A influenza virus. Whether swine influenza virus is capable of causing reproductive failure is undecided at the moment. Piglets from dams infected during pregnancy became ill shortly after birth and harbored chronic infections that reduced growth rate. Prenatal deaths were seen and virus was isolated from the placenta.

Leptospirosis. Leptospirosis is a worldwide cause of reproductive failure in pigs that manifests itself as abortions, mummifications, stillbirths, and weak neonates. Leptospirosis in pigs is mainly due to *L. interrogans* serovar *pomona*, which localizes in the kidney and is excreted in urine. Besides *pomona*, serovars *grippotyphosa, canicola,* and *icterohaemorrhagica* have been isolated from swine in the United States. The spirochetes enter the animal through contact of urine and breaks in the skin, mucous membranes, or conjunctiva. Animals may then establish themselves as shedders and serve as reservoirs of the bacteria. Wildlife (e.g., white tail deer, skunks, opossums, muskrats, rats and squirrels) and domestic dogs have been shown to harbor leptospira. Infected boars have also been incriminated as reservoirs by passing *L. pomona* through semen. In New Zealand leptospiral infection is apparent in piglets from 12 weeks of age (Bolt and Marshall, 1995). Spread occurs primarily because of mixing age groups.

The incubation period of leptospirosis in swine is 1 to 2 weeks, depending on the serovar and the age of the pig infected. Acute leptospirosis is manifested by anorexia, fever, and diarrhea for 1 to 3 days. Chronic infections cause no clinical signs, but bacteria are constantly shed and kidneys show gross lesions at necropsy. Leptospirosis infection is difficult to detect because it affects only a few animals at a time.

In pregnant swine, leptospires are capable of causing a septicemia and crossing the placenta, resulting in abortions, stillbirths, and weak neonates. When infections occur in the last half of gestation, the most characteristic lesions in stillbirths and neonates appear to be focal necrosis, edema, and bloody fluids in the body cavities, along with jaundice. Mild fever and inappetence are the only signs detectable in the sow.

Brucella suis. *Brucella suis* was initially recognized as a major swine pathogen in the 1920s; however, the effects of *B. suis* have diminished because of high standards of management and eradication procedures. *B. suis* can be divided into 9 biotypes, with types 1 and 3 being the primary problems, particularly type 1 because it is found worldwide. Transmission occurs through contact with infected swine through the alimentary tract (contaminated food and water, aborted fetuses) and the genital tract (contaminated semen).

The clinical manifestations of *B. suis* are abortion, infertility, orchitis, and lameness. Death is rare. Abortions may occur at any time during gestation, as early as 17 days after infection. The rate of abortion is highest in females infected through the genital tract. Early abortions are often overlooked in large herds. An indication of infection is a large number of sows returning to estrus 30 to 45 days after conception.

Stillbirths and weak neonates are observed, with mummification being uncommon. Aborted fetuses and the placentas are hemorrhagic, edematous, and autolyzed. *Brucella* is shed through vaginal discharge for up to 30 days after genital infection. Once infection has diminished, most sows regain their proper reproductive capacity following two to three cycles of sexual rest. Control programs for brucellosis have been successful in the United States, but endemic areas may still occur (Christianson, 1992).

Swine Erysipelas. Swine erysipelas (SE), caused by the bacteria *Erysipelothrix rhusiopathiae,* infects swine in three phases: acute, subacute, and chronic. Only acute SE is noted to cause reproductive failure. Infected animals are feverish, anorexic, and depressed and are covered with rhomboid, purple, uticarical lesions and skin necrosis at the ears and tail. SE reproductive failure is manifested by abortion, probably because of the septicemia and subsequent illness in the dam.

Fungal Agents. The ingestion of mold-contaminated feeds can have an adverse effect on swine reproduction. Molds such as *Penicillium, Aspergillus, Claviceps,* and *Fusarium* can produce chemical substances called mycotoxins, which can exist in corn, wheat, oats, barley, cottonseed, and peanut meal and soybeans. The ideal environment for the growth of the toxins occurs when the plants are subjected to cool, wet weather during flowering and a short drying season in the fall. Improper moisture contact during storage (greater than 13% to 14%) promotes mycotoxin formation.

The effects of mycotoxins produced by these various fungal species are diverse. Penicillin and *Aspergillus* are capable of producing ochratoxin, which causes renal necrosis. Aflatoxin, produced by *Aspergillus flavus,* causes reduced feed intake and growth. Ergot alkaloids, produced by *Claviceps purpura,* cause reproductive problems associated with failure of sows and gilts to nurse after farrowing. *Fusarium roseum* produces two mycotoxins—zearalenone and deoxynivalenone—with the former capable of mimicking the effects of estradiol and the latter causing decreased feed intake and vomiting.

Zearalenone has its most profound effects on prepubertal gilts. Low concentrations of the toxin cause hyperestrogenism, swollen vulvas, mammary development, and rectal and vaginal prolapse. In mature sows the toxin has been shown to cause pseudopregnancy, anestrus, weak neonates, stillbirths, and abortion.

The effect of zearalenone on the sexual development of boars has been examined, but no positive conclusions have been drawn. Studies have shown that the effects of the toxin are more severe on prepubertal boars. There is reduced testis development, and studies have shown decreased libido in prepubertal boars fed corn containing zearalenone. Recent studies on mature boars have shown no detrimental effects of the toxin on libido or sperm development. Further research is necessary.

Nutrition and Reproductive Performance in the Gilt and Sow

Prolificacy is the number of viable piglets produced per sow either per year or per breeding lifetime. Prolificacy is influenced by age at first successful mating, ovulation rate and embryo survival at each mating, number of piglets born alive, and the sow's ability to be remated successfully at regular intervals. The literature on nutrition and sow prolificacy has been reviewed (Aherne and Kirkwood, 1985). The protein and amino acid requirements for pregnancy and lactation in swine have also been reviewed (Speer, 1990). The effects of dietary salt during gestation and lactation on reproductive performance of sows have been examined. A decrease in salt concentration in sows' diets from 0.5% to 0.25% or 0.125% reduces birth weight, and a feeding of less than 0.5% salt for more than one reproductive cycle reduces litter sizes at birth and weaning.

The interaction of nutrition and reproductive performance in the gilt and sow are outlined and described here.

Gilt Nutrition. Gilts may constitute 30% to 40% of the breeding females of a herd; therefore the factors affecting gilt reproductive performance will have a significant impact on overall herd prolificacy (Aherne and Kirkwood, 1985).

Age at successful mating is largely dependent on age at puberty. Diets that meet recognized standards of energy and protein content have allowed gilts to express their potential in terms of age at puberty. Under normal conditions of feeding and management, nutrition will have a minimal influence on gilt prolificacy. However, to gain the advantages of a slightly younger age at puberty, maximum ovulation rate, and an adequate fat cover, gilts should be fed ad libitum up to the time of breeding. More feed or energy intake given before mating increases ovulation rate, but high-level feeding during rearing of gilts or in the premating period is also associated with an increased embryo mortality. An increased ovulation rate, combined with increased embryo mortality, therefore does not have a significant effect in final litter size at birth.

Under normal conditions of feeding and management, nutrition has a minimum influence on gilt prolificacy. However, to gain the advantage of slightly younger age at puberty, maximum ovulation rate, and an adequate fat cover, and to ensure against subsequent poor management, gilts should be fed ad libitum up to the time of breeding. Ad libitum feeding of gilts reduces age at puberty. Prepubertal flushing to increase ovulation rate does not lead to increased litter sizes from gilts mated at puberty (Kirkwood et al, 1988).

Pregnancy. Much research has centered on the influence of various levels of feed intake on the relationships between body weight and body condition changes during pregnancy and lactation, milk yield, and subsequent reproductive performance over several parities. The objective is to optimize long-term reproduction at the lowest possible cost.

Long-term reproductive performance is best served by minimizing fluctuations in live weight and fat reserves, thereby avoiding extremes of body condition and subsequent poor performance. This is achieved by small, controlled increases in sow body weight during pregnancy and by feeding according to appetite for restricted periods each day during lactation. Feeding of the sow during pregnancy should be based on requirements for optimum development of the sow and her fetuses. The young sow should receive sufficient feed to enable her to grow to mature size. If a sow has to produce a litter of 10 piglets and gain a total of 40 to 45 kg during pregnancy, the feed requirement for conceptus and maternal gain is about 30%, in addition to that for maintenance requirements. For each degree centrigrade below thermoneutrality (i.e., 18° to 20° C), about a 4% increase in maintenance requirements can be expected; changes in housing associated with increased activity of animals increase the maintenance requirement (Verstegen and den Hartog, 1989). Pregnant gilts and sows in gestation crates with unbedded concrete-slat floors during cold weather (i.e., 10° to 12° C) may have a lower critical temperature than expected and could benefit from additional feed, especially in late pregnancy when the critical temperature is lower than in early pregnancy. Additional feed in late gestation improves reproductive performance in sows. The cost of feeding an additional 31 kg of feed/sow during the last 23 days of gestation was more than offset by the value of the additional sow weight gain, 0.3 pig/litter at weaning, and 2.6 kg of total weaning weight. High-fiber feeds can be used during pregnancy, when energy requirements are relatively low.

Lactation. High-producing sows can easily yield 8 to 9 kg of milk/day when nursing 9 to 10 pigs during peak lactation. By weight, sow's milk has an average composition of 81.2% water, 6.8% fat, 5.5% lactose, 5.0% protein, and 1.0% ash. Peak milk production occurs between the second and fourth week of lactation. At the highest level of milk production, a lactating sow can yield 0.55 and 0.45 kg of milk fat and protein, respectively. As a result, the daily nutrient requirements for lactation are two to three times greater than during gestation. The energy requirements of the lactating sow are related to her body size and body reserves at the beginning of lactation, the number of pigs nursing, her milking ability, feed intake capacity, and other factors such as ambient temperature. If sows are not fed sufficiently during lactation, they use body stores of fat and protein. Sows mobilizing fat stores will lose body weight, which will subsequently be reflected in poor reproductive performance such as delayed estrus after weaning (Kirkwood et al, 1988). Excessive weight loss or backfat loss during lactation will adversely affect subsequent sow reproductive performance. The feeding of a high-energy diet during lactation can increase subsequent litter size, especially second litters. Sows should be fed at least to appetite during lactation, and a higher-energy–dense diet may be beneficial.

The lactating sow requires 5 to 7 kg of feed daily to maintain body weight and condition during lactation. However, even on ad libitum intake, sows fail to eat the required feed consumption and thus lose body weight and tissue. The problem is most acute in primiparous sows, and low feed intake during lactation is recognized as a major factor in postweaning anestrus and impaired reproductive performance. Older animals, those with high suckling load, and thin animals all tend to eat more, with maximum daily intake occurring at 4 to 5 weeks of lactation. Intakes are reduced at high environmental temperatures, but this can be alleviated by wet feeding and by offering a high-energy–dense diet or a high-protein diet. Other factors that influence voluntary feed intake are the breed of pig and the lighting pattern. The reduction in embryo survival after previous short lactation lengths or low-level feed intake during lactation may be due to a reduction in plasma gonadotropin levels or a reduced ovarian response to gonadotropin stimulation. Experimentally, the decrease in embryo number associated with a low level of feeding during lactation can be alleviated by the administration of GnRH.

The literature on the mineral nutrition of the sow has been reviewed (Mahan, 1990). The mineral requirements of the gilt and sow vary with the demands that occur during different phases of the reproductive cycle. Minerals are required for conception, maintenance of pregnancy, lactation, growth, and maintenance. The sow's mineral requirements are highest during late gestation and lactation, and minerals that are supplied from both the diet and tissue reserves contribute in meeting these nutritional needs. The sow is resilient to borderline mineral deficiencies, but longevity in the herd may be compromised under marginal conditions. The reproducing sow will deplete her pool of tissue minerals before litter size, congenital abnormalities of developing fetuses, or milk mineral composition are affected. Inadequate mineral nutrition, especially of calcium and phosphorus, may prolong the duration of parturition, causing an increase in the number of stillbirths, and cause skeletal abnormalities such as osteomalacia, which leads to pathological fractures in sows.

The recent NRC (1999) publication, *Nutrient Requirements of Swine*, lists the dietary mineral level and absolute daily intake of minerals for both gestation and lactation. The percentage values are interfaced with absolute calculations that assume an average daily feed intake of 1.9 kg during pregnancy and 5.3 kg during lactation to meet these needs. Gestation feed intakes are usually in line with these feeding standards, but lactation feed intakes may be less than 5.3 kg/day. Therefore, to meet the daily mineral needs as suggested by the NRC when a lower quantity of feed is consumed, a higher dietary concentration must be provided (Mahan, 1990).

Feed and water deprivation before weaning does not decrease the weaning-to-breeding interval of sows; feed deprivation can actually increase the weaning-to-breeding interval.

Nutrition of Sow after Weaning. The major objectives of nutrition during the period after weaning are to shorten the interval from weaning to breeding and maximize the ovulation and conception rates (Aherne and Kirkwood, 1985). Earlier recommendations included a drying-off period of at least 24 hours after weaning, during which the sow receives no feed or water. This was considered an effective method of shortening and synchronizing the interval to estrus. Recent evidence indicates no beneficial value of this practice. There is no benefit from high-level feeding after weaning, except possibly in primiparous sows or sows that lost a large amount of body weight and condition during the previous lactation. Soon after weaning, sows lose a considerable amount of weight because of water loss and depletion of body tissue, including protein.

Body Condition of Sows. Energy intake affects body weight and backfat changes during gestation and lactation, and these changes in body condition are associated with impaired reproductive performance. Observations of swine producers indicate that subtle changes in nutrition may not affect reproductive performance in commercial swine production systems. Sows gain weight and body condition during gestation and lose weight and body condition during lactation; the effects of these changes are reflected in subsequent reproductive performance. The production goal should be to determine the amount of feed intake that would result in minimum body weight changes from gestation through lactation and postweaning estrus, which would be commensurate with optimum reproductive performance and be profitable.

There are no significant relations between changes in body condition and rebreeding performance of sows. These results suggest that changes in body condition typically observed in sows housed in commercial production units may be too subtle to have an effect on reproductive performance (Esbenshade et al, 1986). The relationships between reproductive performance, body weight, and body condition, and differing body fatness at parturition, differing nutrition during lactation, and differing litter size have been examined (Yang et al, 1989). High-level feeding in lactation improved production and efficiency benefits in both primiparous and multiparous sows, whereas pregnancy feeding to attain a target of 20 mm rather than 12 mm of backfat at parturition was of benefit for primiparous sows. The timing of postweaning estrus in primiparous sows is not dependent on a minimal threshold of body fat. The interval to estrus is more closely related to metabolizable energy intake during lactation than to body-fat percentage (Johnston et al, 1989).

Formulation of Sow Diets. Swine producers continue to report a variety of problems associated with the performance of the gestating and lactating sow. The common problems are poor reproductive performance and reduced longevity of sows in the herd. Many swine producers do not regularly evaluate their feeding programs to check the accuracy of their diet formulations and mixing procedures. The nutrient content of feedstuffs can also vary considerably, depending on the source. Analysis of feed samples from the gestation and lactation diets of a large number of swine farms revealed that the percentage of samples failing to meet the nutrient levels specified by the NRC for crude protein, calcium, and phosphorus ranged from none to 24%, depending on the nutrient. More care is needed in formulating diets for the sow herd, and mixing and sampling errors must be minimized by using scales and following directions for proper mixing.

Housing of Sows During Gestation

Confinement housing of sows has become the predominant housing system because of its increased labor efficiency. Comparison of reproductive performance in sows housed during breeding and gestation with that in sows kept in outside lots, in a climate where ambient temperature reaches a minimum of −40° C in the winter and a maximum of 38° C in the summer, demonstrated that housing sows in outside lots had no effect on litter size at birth (Dyck et al, 1985). For sows kept outdoors, the litter size at weaning was larger and the culling rate was lower than for sows housed in confinement, which suggests that greater space per sow and cleaner air may be important factors in maintaining healthy sows.

A variety of housing systems have been used for nonlactating sows (Petherick and Blackshaw, 1986). They may be kept in groups outdoors in simple shelters, or in small groups indoors in pens with or without bedding, and facilities for group or individual feeding. Most gilts and sows are kept in individual stalls or cubicles throughout gestation. There are advantages and disadvantages with each system relative to the sow, the livestock attendant, the environment, and the cost. Keeping sows in groups is cheapest, but aggression among sows can be a problem. The providing of individual feeders, which eliminates fighting at feeding times, adds considerably to both the cost and the space requirement of the housing system. Individual housing in stalls or cubicles is relatively inexpensive and has the advantages of ease of handling and monitoring and the elimination of fighting. However, there is growing concern about the welfare aspects of the virtual lifelong restraint that these systems impose on sows. Individual housing of sows may be associated with certain stereotyped behaviors and may have an effect on reproductive performance, but these associations have not been defined clearly.

Farrowing Gilts and Sows

Periparturient Behavior of Sows. Periparturient behavior in swine can be divided into prepartum, parturient, and postpartum phases (Hurnik, 1985). In the last month of pregnancy, sows show an increased appetite, their movements become slower, and recumbency is more frequent. The mammary glands begin to enlarge about 3 weeks before parturition, and pregnant sows show increased responsiveness to the vocalization or visual appearance of piglets. During the last week of pregnancy, especially 3 to 4 days before parturition, the appetite decreases and the genitalia and mammary glands enlarge grossly. If liquid serous discharge can be expressed from the teats, farrowing will occur within 48 hours; if colostrum can be expressed, farrowing will occur within 24 hours. If given the opportunity, 1 day before farrowing, the sow will build a nest; if there is no opportunity, she will make movements with her legs indicating the desire to do so. Within the last several hours before farrowing, restlessness and an increased respiratory rate are obvious and the sow calms down. With approaching delivery, lateral recumbency is common and the sow enters the first stage of labor, which lasts from 1 to 2 hours and is accompanied by an increased respiratory rate, intervals of abdominal straining accompanied by vigorous tail switching, occasional grunting, and grinding of the teeth. Immediately before the expulsion of each piglet, tail switching and abdominal straining can be observed. Approximately 30% of piglets are delivered in posterior presentation, and in about 70% of cases, the umbilical cord remains intact until movement of the piglet or the sow effects breakage. Piglets are often fully surrounded by fetal membranes; in natural circumstances, they either free themselves by their own effort or suffocate. Approximately 70% of all mortalities result from suffocation, apnea, or other causes occur in piglets delivered in the latter part of the expulsion phase. The average interval between expulsions of two consecutive piglets is about 15 minutes. Duration of the second stage of labor is usually about 2 to 4 hours but may be as short as 30 minutes or as long as 10 hours. The third stage of labor may start during the delivery stage, but complete expulsion of the placenta generally occurs within 4 hours of the birth of the last piglet.

Postpartum Phase. In the postpartum phase, normal healthy piglets are active soon after birth. They may be apneic for 5 to 10 sec, but after a few light coughs and a short period of panting, regular breathing begins. Within a few minutes of freeing themselves from the placental membranes, they are able to walk, and within 30 minutes they usually succeed in finding a teat. During the first period of nursing, the levels of oxytocin are high, which provides for an extended period of milk letdown. The sow is almost continually available for sucking by the piglets, which makes colostrum available at practically any time during the expulsion and placental stages of labor. Cyclical nursing, the second period of nursing, starts to develop during the second half of the first day postpartum and is characterized by regular periods of milk letdown and socially synchronized suckling by the piglets. Sows seem to be actively involved in this process by controlling the approach of the piglets to the mammary gland. By the end of the second postpartum day, the nursing cycle of normal, healthy litters is fully stabilized. Cyclical nursing occurs at regular intervals of about 1 hour. A typical nursing cycle consists of several distinct phases such as assembly, nosing, slow sucking, true sucking, and departure. The sow-litter bond develops at the initiation of cyclical nursing, and thereafter the bond is strong. Any distress call of the piglets, alarm calls by adjacent sows, or appearance of unfamiliar objects, animals, or people triggers an immediate and sometimes aversive reaction.

Cross-fostering in swine is relatively easy to accomplish, if the alien piglets are introduced within 2 days postpartum. Any aggressiveness of the sow is usually diminished after sucking is initiated. Piglets develop a specific positional association with individual teats known as the teat order, which is characterized by consistency of teat choice on consecutive nursings. The development of teat specificity takes place over a period of 3 days in four phases: teat seeking, teat sampling, teat defense, and teat maintenance. Not being fully homeothermic, piglets experience a drop of about 2° C after birth and recover in about 1 day. A distinct behavioral characteristic of young piglets is the seeking of thermal comfort during resting by close aggregation to litter mates in areas of relative warmth, particularly during the first 2 weeks of life, when their physiological thermoregulation is still developing.

The foregoing knowledge is an important prerequisite for successful management of farrowing operations and more efficacious attainment of production potentials in swine. Traditionally, improvements in farrowing-house performance have been achieved by giving attention to basic hygiene and husbandry factors, and the accepted farrowing-house mortality has been 8% to 10%. However, many swine farms can get this mortality rate down to 5% with a better understanding of the needs of the farrowing and nursing sow. The factors that must be considered include: good records, pen layout, design of farrowing crates, bedding, stress factors, feeding systems, supervision of farrowing, fostering of piglets, and the education and training of the staff in the farrowing house.

Pregnant sows and gilts should be moved into the farrowing facility at least 6 days before the expected farrowing date. In a batch-farrowing system, a group is usually brought into the farrowing crates at least 1 week before the mean expected due date. This 1-week period allows for individual variations in gestational length, which will vary up to 4 days, and for an adequate period of adjustment to the farrowing crate. The farrowing crates should have been cleaned, disinfected, and left vacant for at least 3 days before pregnant sows are moved into them. In addition, all sows and gilts should be washed before entering the farrowing facilities. This removes gross fecal contamination of the skin and reduces the population of the bacterial flora of the skin, which aids in the control of bacterial diseases of the newborn piglet.

Dystocia and Perinatal Mortality. Parturition in the pig is relatively simple, and dystocia and uterine inertia are uncommon. The duration of farrowing is approximately 2 hours, and a piglet is born approximately every 15 minutes. Posterior presentations are common, but most piglets are born in a dorsosacral position. The most common cause of perinatal mortality is intrapartum death of piglets born in the last one third of the litter. Premature rupture of the umbilical cord is a major factor in the cause of intrapartum deaths, which may be related to prolonged farrowing times. In approximately 70% of intrapartum deaths, the piglets are alive at birth, although the clinical signs of viability are often limited only in the presence of a slow heartbeat, which gradually fades and ceases within several minutes of delivery. These piglets are in a state of hypercapnia and acidosis, and resuscitation may be possible.

Surveillance and supervision of farrowing to minimize perinatal mortality includes obstetric assistance of sows with dystocia, resuscitation of piglets that are almost dead as a result of intrapartum asphyxia, removal of placenta envelopes to prevent suffocation of piglets, placing of piglets under the heat lamp immediately after birth to prevent hypothermia and crushing by the sow, assessment of the sow's milking potential and interfrosting accordingly, identification of

piglets that did not suck early enough, clipping of all piglets' teeth, and treatment of piglets' navels with an antibacterial spray immediately after birth.

Induction of Parturition. Farrowing may be induced and synchronized in a group of sows by using a single injection of a prostaglandin or its analogs. A successful induction of parturition has practical application in commercial swine units operating a batch-farrowing system (Podany et al, 1987). Individual sows within groups weaned on the same day usually commence their postweaning estrus between 4 and 8 days later. If these animals are served over a 4- or 5-day period with a gestation period lasting between 114 and 118 days, the farrowings normally extend over about 10 days. With an induction treatment initiated just after the first natural farrowings, it should be possible to reduce the farrowing range for an individual group 5 or 6 days to maintain a better batch effect. This should increase the efficiency of use of the farrowing facility. A reduction of 2 to 3 days in the interval from first to last farrowing could allow more groups through the unit in a fixed time and give 1 or 2 extra days for cleaning and sanitation between groups. Concentrated farrowings would have other potential advantages: piglets could be transferred readily from larger to smaller litters, routine activities like iron injections or castrations could be carried out on more piglets at the same time, and the age range at weaning would be reduced. In addition, weekend and holidays farrowings could be avoided, which would minimize labor requirements during these periods.

Successful induced farrowings allow a high percentage of farrowings to occur at predetermined times, when maximum surveillance and supervision can be provided to minimize the incidence of perinatal mortality.

The prostaglandins are usually given 1 to 3 days before the expected farrowing date (e.g., Days 112, 113, or 114 of gestation). The response varies with the type of prostaglandin used, but in most cases more than 60%, and in some cases more than 90%, of treated sows commence farrowing between 18 and 36 hours after administration of the prostaglandin. The administration of oxytocin 6 hours after the prostaglandin induces the most rapid onset and the greatest synchrony of farrowing (Kirkwood and Aherne, 1998). The use of fenprostalene and oxytocin on Day 114 of pregnancy caused a reduction in the duration of farrowing compared with the prostaglandin alone (Stephens et al, 1988). Induction of parturition on Day 110 of gestation may be associated with a slight increase in perinatal piglet mortality compared with inductions on Days 112 and 113. It is essential to have reliable breeding records in order to induce farrowing 2 to 3 days before the expected natural farrowing date. New prostaglandin analogs are being made available and are as effective as cloprostenol.

Control of Diseases of Farrowing Gilts and Sows

Mastitis-Metritis-Agalactia Syndrome. The most important disease complex of the sow at the time of farrowing is mastitis-metritis-agalactia (MMA) syndrome, also known as lactation failure or periparturient hypogalactia syndrome. The details of the internal-medicine aspects of the disease are described (Radostits et al, 2000), and a review of the subject is available. While the etiology has been controversial, there is considerable clinical and laboratory evidence that toxemic mastitis, most commonly resulting from *E. coli*, is the predominant lesion, and the metritis is usually not present. It is suggested that the endotoxin suppresses the release of prolactin, which causes a decline in milk production.

Therapy includes the use of oxytocin, antimicrobials, and supplemental feeding of the piglets.

The prevention of MMA syndrome in the sow is crucial because of the effects of agalactia on the newborn piglets. It has been difficult to develop a rational approach to prevention, because the disease has been considered a complex syndrome caused by several different factors. However, the control of infectious mastitis would seem to be of major importance. Farrowing crates should be vacated, cleaned, disinfected, and left vacant for a few days before pregnant sows are transferred from the dry-sow barn and placed in the crates. Pregnant sows should be washed with soap and water before being placed in the crates. Farrowing crates must be kept clean and hosed down if necessary, particularly a few days before and after farrowing, to minimize the level of intramammary infection. In problem herds, it may be necessary to wash and disinfect the skin over the mammary glands immediately after farrowing.

Other causes of lactation failure include failure of the milk ejection reflex, psychogenic agalactia in nervous or aggressive sows, and failure of mammary development due to ergotism.

Antimicrobial agents used prophylactically appear to be successful in controlling some outbreaks of MMA. A sulfadimidine-trimethoprim-sulfathiazole combination fed to sows for 3 to 5 days before the expected farrowing date may reduce the incidence of MMA in problem herds.

The use of prostaglandins for the induction of parturition has not been associated with a consistent decrease in the incidence of MMA. Some field trials have shown a reduction in incidence, whereas others have had no effect.

Sow Hysteria. Some sows show aggressive behavior at parturition and attack their own piglets, resulting in wounding or death of the piglets. This behavior seems to be more common in gilts. Examination of the frequency, environmental influences, and heritability of aggressive behavior in a large number of litters indicated a heritability between 0.25 and 0.50, and selection against aggressive sows at parturition through the selection of boars and gilts from nonaggressive dams only slowly reduces the frequency of occurrence (van der Steen et al, 1988).

To minimize the stress on the sow of adjusting to the farrowing crate and facilities, the sow should be placed in the crates at least 1 week before the expected date of farrowing. The nature and composition of the diet fed to the sow while in the farrowing crate should not be changed. The only necessary change is to increase the daily intake compared with the intake during the dry period, beginning on the day after the sow has farrowed and continuing thereafter as lactation proceeds. The inclusion of bran at the rate of one third to one half of the total diet for 2 days before and after farrowing has been recommended to prevent constipation. In some herds, the use at all times of lucerne meal as 15% of the diet has been recommended. However, under intensified conditions, it may be impractical to prepare and provide these special diets on a regular basis. Although field observations suggest that a bulky diet at the time of farrowing minimizes the incidence of toxic agalactia, there is little scientific evidence to support the practice.

Pyelonephritis and Cystitis. Other diseases of the sow that may occur within a few days before or after farrowing include pyelonephritis and cystitis caused by *Eubacterium suis*. Cystitis and pyelonephritis resulting from *E. suis* may occur in several animals over a period of several months. The ubiquitous nature of the organism may make it difficult to eradicate from a herd. The use of modified and medicated early-weaning programs using antibiotics failed to eliminate *E. suis* from the male population (Dee et al, 1994).

Erysipelas. Epidemics of infectious disease are uncommon in sows raised in confinement, presumably because of age-dependent immunity and lack of exposure to pathogens

such as *Erysipelothrix insidiosa*, which may cause epidemics in nonvaccinated exposed animals.

Causes of Sow Mortality

Only a few large-scale studies of sow mortality have been published, and most are based on pigs submitted for necropsy examination. In a study of sow mortality in 75 Danish herds, an average mortality of 4.6% with a range from 0.4% to 11.4% was recorded (Christensen et al, 1995). Sow mortality rates reported from England, France, and Canada were 4.0%, 3.7%, and 3.3%, respectively. In a Danish study of sow mortality based on carcasses being submitted to a rendering plant and in which a clinical history was available, the distribution of likely causes of death or euthanasia was as follows: leg weakness (28.5%), diseases associated with late pregnancy and farrowing (20.9%), digestive tract disease (17.1%), urinary tract (13.1%), physical injuries (10.7%), and others (9.5%). In another group of sows submitted to the rendering plant with no known history, the distribution of likely causes was as follows: leg weakness (16.1%), diseases related to late pregnancy and farrowing (10.7%), diseases of the digestive tract (21.2%), urinary tract (15.2%), others (15.0%), and unknown causes (21.8%). The overall mortality rate was estimated to be 5% to 6%. Mortality rate increased with increasing herd size, and in herds with more than 100 sows the mortality rate was three times the mortality rate in herds with fewer than 50 sows (Christensen et al, 1995). The proportion of diseases of the digestive tract may have increased in the last 20 years. Gastric dilatation is particularly common and may be related to the intensification of production.

In a 1-year survey of 106 herds containing 2488 sows, the mortality rate was 4%. The major causes of death were complications of parturition, cystitis, nephritis, endocarditis, and acute hemorrhage. Bacterial infection was an important factor in 43% of the deaths.

The causes of death in sows examined in a diagnostic laboratory over a period of 8 years included the following: sudden death due to *Clostridium novyi* (31.6%), cystitis-pyelonephritis (20.0%), abdominal disease (gastric dilatation and torsion, gastric rupture, torsion of a lobe of the liver, and rupture and torsion of small and large intestines) (11.8%), perforated gastric ulcer (4.5%), splenic torsion (4.0%), heart failure (3.6%), septic pneumonia (3.8%), alimentary lymphosarcoma (2.7%), endometritis (2.2%), and no diagnosis (5.5%) (Duran, 1994).

In a study of sow mortality in herds in France, with an average mortality of 6.4%, the risk factors for high sow mortality included multiplier herds compared with commercial farrow-to-finish herds (Abiven et al, 1998). Farms in which dry sows were housed in individual stalls were at higher risk of experiencing a high mortality rate than farms with tethers for dry sows. Feeding lactating sows ad libitum was more risky for mortality than a feeding plan in which the maximum daily amount of feed provided to sows was lower than 8 kg and reached in early lactation. Providing of three meals a day instead of two to dry sows decreased the odds of high mortality. An average of weaning at 28 days or more and/or small average litter size at birth of 12 piglets or less were associated with higher odds of high sow mortality.

Housing and Space Requirements for Gilts and Sows in Confinement

Traditional Farrowing Pens. Before about 1960, a sow and her litter were kept in square or rectangular pens constructed in rows along a central feeding passage. These pens were commonly multipurpose; they could house a dry sow, a lactating sow and her litter, or perhaps a boar. Piglet mortality from crushing was a problem, and some pens had a protective rail along the walls to protect the piglets when the sow lay down. The pens were bedded with straw and cleaned daily. In some cases, a portable wooden farrowing crate was placed in the stall before farrowing and during lactation.

Advent of Farrowing Crates. Beginning around 1960, the farrowing crates were fixed to the floor in rows in farrowing rooms, and the sow was released twice daily to be fed. The farrowing crate had an infrared lamp–heated creep area for the piglets. From that beginning until the 1990s, many modifications of the farrowing crate have been developed, including the dry sow crate for housing the sows after weaning and during gestation. Tethering sows individually by the heartgirth or the neck was used for some years but soon fell into disfavor because of welfare issues. When pigs are kept extensively in an outdoor system with a large living space, their welfare is normally considered adequate.

Under current conditions, pigs are kept indoors during their entire life, and the number of pigs per unit is steadily increasing. Considerable progress has been made in the last 3 decades in the design of crates for pregnant and lactating sows. The requirements for a good breeding area include good contact, both physical and visual, between sows and boars; maintenance of a reasonable temperature range; feeding systems adequate to the system of management; ease of stock movement; ease of stock observation; and a well-designed service area. Boars are usually penned individually. Pregnant sows are commonly kept in individual stalls with straight or sloped sides and slatted floors in the rear and the feeder and waterer in the front. Farrowing houses are designed based on years of experience to produce a high survival rate in the piglets. The farrowing rooms are heated, and the creep areas of each farrowing crate have supplemental heat for the piglets.

Sow Crate Design and Comfort. The major concerns about sow crate design include the dimensions; the slope of the sides, which allows the sow to lie down and get up easily without injuring the piglets; the floor surface; the comfort of the creep area for the piglets; the ease of cleaning; the ease of removing the animal from the crate for breeding and other reasons; the welfare aspects of keeping animals in such confinement; and the effects of confinement on productivity.

The practice of confining sows in stalls or crates throughout gestation and lactation has become widespread in modern pig production. Surveys in the United Kingdom found that 87% of sows farrow in farrowing crates, and 75% of producers with large herds confine gestating sows in stalls (Baxter and Schwaller, 1983). Gestation crates of various dimensions, shapes, and fabrication materials are used widely (McFarlane et al, 1988). Gestation crates make it possible to feed pregnant sows and gilts individually; to keep them separated, which reduces fighting and thus injuries; to conserve building space and heat; and to facilitate waste handling. In most crates, however, sows and gilts can walk only a step or two and are unable to turn around.

Close confinement, which prevents the sow from turning around, has been a welfare issue over which much concern has been expressed. The Brambell Committee (Brambell, 1965) on farm-animal welfare concluded that "pregnant sows should not be kept without daily exercise in quarters which do not permit them to turn round." The Committee also stated that "an animal should at least have sufficient freedom of movement to be able without difficulty, to turn around, groom itself, get up, lie down and stretch its limbs." These animals might need to walk and turn around. Depriving them of opportunities to do so might affect their health, performance, and overall well-being. The Swedish code of recommendations for the welfare of animals was more

forceful, stating that "permanent tethering of pigs is forbidden" (Swedish Ministry of Agriculture, 1989).

The Farm Animal Welfare Council (1988) in the United Kingdom recommended that future trends in housing the dry sow should be away from the use of stalls and both girth and neck types of the tether system, and that the government should introduce legislation as a matter of urgency to prevent all further installations of units of these designs. The ban of permanent single housing of sows in Germany forbids neck tethering and states that after weaning, sows must be allowed free movement daily over a period of 4 weeks (Lehmann, 1990).

A symposium held in France in 1983 dealt with the welfare of confined sows. The four major topics discussed were productivity, physical health, behavior and physiology, and new approaches. Subjects discussed included the effects of confinement on productivity of sows and gilts, tethered versus loose sows, diseases and injuries affecting confined sows, ways to delineate the sow's welfare needs, an environmental model for the sow's physical and behavioral needs, and stereotyped behavior in tethered sows (Aumaitre and Dantzer, 1984).

The social space requirements of pigs is a concern. Pigs have social space requirements because of certain aspects of their sociality, and groups of pigs require more space than just the sum of the individuals' space requirements (Baxter, 1989). They do not appear to have personal space around their heads or bodies that other pigs are not permitted to enter, which regulates interindividual distances. Their tolerance of other pigs is dependent on what they are doing and, in particular, whether they are in possession of a resource that they want to defend. The social space requirements could be met by giving the pig as much space as necessary or by changing the pig's environment in such a way that the social space requirement is reduced to fit the existing space allocation. For example, this could be achieved by providing trough barriers to reduce aggression during feeding.

Animal Welfare Concerns. Welfare has been defined as a state of complete mental and physical health, in which the animal is in harmony with its environment. The welfare of animals relates to the degree to which they can adapt without suffering to the environments designed by humans. As long as a species remains within the limit of the environmental range to which it can adapt, its well-being is assumed (Stephens, 1989). It can be seen from these definitions that the mental state of the pig is vitally related to its welfare. Therefore the normal behavior of the pig and changes induced in that behavior by intensive husbandry methods are important indicators of the pig's well-being in such environments. When the pig undergoes behavioral changes in order to adapt to its environment, the nature of those changes depends on the stimulus. When the stimulus is simple, such as a change in ambient temperature, the response to the change in the environment is usually obvious and easy to interpret. For example, piglets reared in a group respond to a lowering of ambient temperature by huddling together. This reduces the surface area exposed to the environment, and the total energy expenditure of the piglets can be reduced by as much as 40%. However, the mental state of the pig is much more difficult to assess, particularly if the animals are producing the desired end product satisfactorily. The relations among environmental changes, abnormal behavior, and mental well-being are the subject of much investigation (Stephens, 1989).

The way in which farm-animal welfare is appraised has three faults: (1) welfare is not systematically analyzed; (2) welfare requirements are described in little detail; and (3) there is no published technical justification for the recommendations. An approach that can help to overcome these problems has been suggested (Baxter and Baxter, 1984). The method attempts to describe sow welfare as the sow perceives it, and then to translate each welfare element in quantifiable variables with defined boundaries of welfare acceptability. Such an approach would improve the depth of investigation of welfare requirements, give the codes of recommendations more consistency over time, and lead to greater longevity.

Sow Crate Design. Despite the widespread use of farrowing crates and the large and growing number of designs available, relatively little systematic investigation has focused on elucidating the effects of sow crate design on the animals that reside in them (Parfet et al, 1989). At the present time, there is no one sow-crate design that is better in all respects than others. However, research indicates that many factors must be considered in choosing a sow crate design, and that piglets are remarkably adept at coping with the environment with which they are provided (Parfet et al, 1989). It seems that crate dimensions tend to affect the behavior of both the sow and the piglets more so than side type, and space-restrictive crate dimensions are more important determinants of health and production (Parfet et al, 1989). The well-being of piglets depends on several factors, including social interactions, the care provided by the sow, and the general environment. The farrowing crate is a major part of the pig's immediate environment in modern swine-rearing systems. Its use has been associated with decreased piglet mortality because of crushing, but the mortality rate during the preweaning period still averages around 15%.

The effects of confinement of sows before breeding and during pregnancy and lactation are noteworthy (Baxter, 1987). Close confinement causes stress. When sows or gilts are confined by tethering for the first time, they demonstrate a panic reaction and undergo a period of intense physical activity directed at escaping from confinement, which lasts an average of 45 minutes. After the escape response, sows typically become very inactive or unresponsive; this state is best described as apathy. While sitting or standing, the sows adopt a hanging-head posture with their eyes half or fully closed and they lean against the bars of the stall. This period of unresponsiveness may last for up to 16 days. By about 10 weeks after tethering, sows will perform regular stereotyped behavior. Most of these stereotyped behaviors are nosing or mouthing activities, which are considered coping responses that help the sow to adapt to adverse aspects of confinement. These stereotyped behaviors can be eliminated and escape-related behaviors reinstated by administering naloxone, which specifically blocks naturally occurring opiates such as endorphins, which are believed to play an important role in any adaptation to stress (Baxter, 1989). The physiological, behavioral, and production responses of confined sows indicate that when sows are tethered individually or housed in pairs, they are in chronic stress compared with being kept in groups indoors or outdoors; however, there is no clear welfare advantage to housing dry, adult pigs in a more extensive natural environment (Barnett et al, 1985). Housing groups of adult gilts with a space allowance of 1 m^2/gilt compared with an allowance of 2 m^2 or 3 m^2 causes a significant elevation of plasma free-corticosteroid concentrations. Dry sows seem able to adapt to close confinement such as tethering, and there appears to be no disadvantage in terms of sow productivity (Parry, 1986). Confinement of sows in farrowing crates does appear to cause them some degree of stress and does seem to prolong the duration of gestation and farrowing interval (Backstrom et al, 1994), but this does not significantly increase the incidence of perinatal mortality or postnatal productivity. The confinement of sows can affect their health because of trauma or injuries. Field studies in Norway found the prevalence of claw lesions in sows is increased in

confined herds, compared with herds with loose-housing (Gjein and Larssen, 1995a,b,c)

Group Housing. Some commercial producers in North America are incorporating group housing of gestating sows into new, large, total confinement units. These group pens frequently have 40 to 80 animals/pen and straw bedding. These systems appear to provide more natural grazing, movement, and social activities. They may also stimulate increased intakes of fiber during late gestation. However, the disadvantages include increased labor input, increased environmental ammonia levels, and the need to handle manure in semisolid form. In addition to potential welfare benefits, these group facilities may be less expensive to build and maintain. It is likely that modifications in construction and management of these group-housing sow pens will resolve some of these disadvantages.

Modified Gestation Crates. Gilts kept in modified gestation crates that allow them to turn and walk do turn several times daily, but the turning does not seem to be motivated by any particular need (McFarlane et al, 1988). When outdoors, sows may walk nearly 2000 m/day. Sows in an indoor pen with eating, lying, and dunging areas close to one another walk an average of 200 m/day. In crates designed to allow walking, pregnant gilts walked 130 m/day (McFarlane et al, 1988), which may be related to the need to move to one end or another to turn.

Farrowing crate design may influence within-litter variance in piglet weights at 14 days of age. Within-litter variance can be significantly higher with horizontal-bar crates than with vertical-bar crates (Thompson and Fraser, 1986). It is suggested that the crate design did not influence the total intake of milk of the litter but did influence the evenness of its distribution to different litter mates. It is possible that the horizontal-bar crates make it more difficult for less competitive piglets to nurse.

In traditional, unconfined farrowing systems, straw plays an important role as a substrate for nest building by the sow. The nest provides both physical cushioning and thermal insulation for the newborn piglets, improving their chance of survival in a hostile environment. In modern farrowing systems, perforated floors are in common use; straw is not used routinely, which makes cleaning much easier; and heated farrowing houses and infrared lamps in the creep area provide the heat necessary for the piglets. The provision of straw in farrowing crates seems to have no effect on farrowing results or on piglet productivity.

Flooring in Farrowing Pens. Flooring in farrowing pens must satisfy a wide variety of criteria. Management considerations dictate that floors must be durable and easily cleaned, but the demands of management and the needs of the animal may conflict. Concrete floors, although durable and easily cleaned, are hard and abrasive. Perforated floors, designed to improve hygiene and save labor, are available in a variety of forms but are not suitable for farrowing pens. In any farrowing system, cleanliness is very important. When the sow is confined in a farrowing crate, she cannot maintain separate dunging and lying areas as she would if more space were available. Therefore she requires a floor that drains well and allows frequent manure removal. On the other hand, the piglets have a different requirement for voiding feces and urine. The incidence of knee and teat damage in suckling piglets varies widely among different floor types. Morbidity, mortality, and external injuries are greater in piglets housed in farrowing crates with a partly metal-slatted floor than on a solid floor with straw bedding (Vellenga et al, 1985). This association extends into the rearing period of the weaned piglets, in which morbidity, mortality, and external injuries were greater in piglets reared in the slatted-floor system.

The effects of the types of farrowing-crate floors on health and productivity of piglets and sows have been examined. The preweaning growth rate of piglets kept on raised, perforated floors was higher than that of piglets kept on mostly solid floors, but there were no differences among the different perforated-floor types studied. It is suggested that there is less heat loss in piglets raised on perforated floors than in those raised on concrete floors, and the perforations allow the liquid to drain; therefore the piglets are drier. The best floor for piglets may be a plastic-covered woven wire, which provides grip but is not abrasive. Injuries to the teats and knees of piglets occur more frequently on old cement or punched metal floors. On the other hand, the incidence of leg abrasions and teat injuries of sows may be greater on fully-perforated, plastic-covered floors, which may be slippery compared with different types of solid floors. Floors of plastic-covered expanded metal or concrete floors with concrete slats at the rear cause sows to move their hind feet a shorter distance and to make fewer foot movements while rising than did floors of fiberglass or perforated metal slats.

Comparison of Loose and Confined Housing. The health and welfare of pregnant sows in loose housing and confined housing systems in Norway have been compared. Vulval lesions were found in sows in loose housing and were related to biting by other sows (Gjein and Larssen, 1995a). The mean proportion of sows with body lesions was 13.1% in the loose-housed sows and 4.0% in the confined sows. Aggression between sows was the main cause of lesions in the loose-housed sows; decubitus ulcers were the main body lesions in confined sows. Sows in loose herds that were not feed additional roughage feed were at greater risk of body lesions. Claw lesions are common in sows kept in loose housing and confinement (Gjein and Larssen, 1995b). The mean herd prevalence proportion of sows with major claw lesions in loose-housing herds with partly slatted floors was about twice as high as in the herds with confined herds. The prevalence of claw lesions was lowest in sows kept in loose housing with deep straw litter (Gjein and Larssen, 1995c). The risk of lameness increased with higher claw lesion score and with the presence of claw infections (Gjein and Larssen, 1995d).

Decubitus Ulcers in Farrowing Gilts and Sows. Decubital ulcers commonly develop over bony prominences of the scapula, hip, mandible, tarsus, cubital joints (elbows), and carpus in sows housed on concrete and other hard floors. A high incidence occurs around the time of farrowing and early lactation, followed by rapid healing after weaning. It is considered a multifactorial disease and risk factors include floor type, moist skin from drip coolers, uninterrupted recumbency during parturition, reduced activity during lactation, and body condition (Davies et al, 1997). Factors such as floor type are important, but other physiological and behavioral factors of periparturient sows (e.g., body weight, body condition, and mobility of late-gestation sows; duration of farrowing; and patterns of recumbency) may be important. Ulcers on the shoulders occurred at the rate of 16% by Day 5 after farrowing; a peak incidence of 48% occurred by Day 12, and all ulcers had resolved by Day 68. The primary cause is unrelieved pressure or shearing forces that cause ischemia of the skin and subcutaneous tissues. Bony prominences with minimal soft-tissue covering are at greatest risk, because they have a high compressive stiffness to deforming loads. The lesions are transient, but the high prevalence may be an animal welfare concern. More field research including controlled studies of various floors is required.

Space Requirements for Gilts and Sows in Crates. The space necessary to allow a sow to stand up and lie down without touching the crate has been estimated (Curtis et al, 1989). The hypothetical 95th-percentile, 250-kg, North

American sow would require a crate approximately 220 cm long and 86 cm wide.

In the ideal farrowing crate, the sow should be able to stand up with ease, lie down without touching the crate, nurse her piglets comfortably, and be able to move away if she is squeezing a piglet; the floor should be self-cleaning or easily cleaned; the creep area should be attractive to and comfortable for the piglets, and the feeders and waterers for the sow should be easily accessible. The crate should allow the sow to perform prelying rooting and pawing behavior and to get any piglets in the danger zone awake and active before she lies down. The crate should also assist the sow in lying down under control and with a minimum of slipping. The dimensions of the crate should be easily adjustable for width, length, and height. The lower bars, which accommodate the sow when she is lying down and provide access of the sow's udder to the piglets, may be vertical, horizontal, or bowed (Curtis et al, 1989). Comparisons of different designs indicate that no one crate design combination is better in all respects than all others, but relatively small design differences can affect the health and performance of the animals. Raising the lower straight bar from 20 to 25 cm above the floor decreased knee lesions at 21 days after birth and increased piglet weight.

The slope of the sides of the farrowing crate has been examined. In the straight-rail crate the sides are spaced equally at the top and bottom. In the flared-rail crate the sides are narrow above and wider below. The finger crate has four straight horizontal bars spaced equally apart, with six prongs attached to the lowest bar and angled away from the sow, which allows the sow to lie down comfortably and provides good access of the piglets to the udder. In the Ottawa crate the sides are spaced well apart at the sow's standing height but are angled inward near the floor to restrict the sow's lying area and to prevent the sow from dropping suddenly onto one side.

Edinburgh Family Pens. The Edinburgh Family Pen System of Pig Production is an alternative system of pig production designed around the behavior and welfare of the pig (Kerr et al, 1988). The Family Pen System arose from the interpretation of observations made on a group of sows kept in 1.23-ha area of hill land, which involved detailed study of the animals to establish their behavior in a natural habitat. These studies identified those physical and social factors of the pig's environment that were judged important for social organization. Each unit was made up of four sows and their offspring housed in four pens, each of which comprised a nest area, activity area, peat area, and connecting feces corridors. The sows remain in the unit with a stable group composition for the whole of their breeding life. A familiar mature boar joins the group 2 to 3 weeks after farrowing. The sows suckle their piglets for 10 to 12 weeks. Estrus invariably occurs during lactation, and sows are successfully mated during lactation. Growing pigs remained in the unit with their dams until they reached slaughter weight, at which time they were sent directly from their pens to slaughter.

Outdoor Pig Production. The number of outdoor sow herds has increased significantly in the last decade in the United Kingdom, France, and Denmark (Mortensen et al, 1994). Productivity in outdoor systems is much more dependent on the climate than indoor production systems. This requires adjustment of management procedures to meet changing weather conditions. In Denmark the same average productivity can be achieved in outdoor sow herds as in indoor herds, although performance variation is greater in outdoor herds. In the most successful herds production performance was similar to that of the best indoor sow herds. The results indicate that outdoor production comprising gestation and lactation until weaning at 4 weeks is a realistic alternative to indoor production. Capital costs are approximately one third of that of indoor production.

Culling of Gilts and Sows

Culling Rates. The removal or culling of nonproductive sows and gilts and the introduction of replacement gilts are essential parts of maintaining herd productivity at a constant, high level. The reasons for culling sows and the rate of culling may be influenced by many factors, such as housing, genotype, management policies, time of year, disease, nutrition, market trends, and tax policies. Average annual culling rates range from 30% to 50%, with a high degree of variability among farms (D'Allaire et al, 1987). In many herds the culling rate has been suggested to be too high, causing an increased proportion of gilts in the breeding herd and therefore causing a lower-than-optimum mean litter size. In an Ontario study of 30 farrow-to-finish herds over a 2-year period, the culling rate of sows was high at 44%, with a wide herd-to-herd variation from 16% to 100%. Surveys have found that 50% to 67% of culled sows have had three or fewer litters before being culled; this indicates that many sows are removed before reaching maximum productivity, which occurs between the third and sixth parities. Conversely, herds with low culling rates may contain sows that have passed their most productive parities. Such herds may have a lower-than-optimum mean litter size and a high stillbirth rate.

The culling rate is a statistic that is often used and misused. The culling rate is defined as the number of sows shipped per year divided by the average number of bred gilts and sows in the herds. There is a need to carefully examine the reasons for culling and the year-to-year variation in culling rates (Christensen, 1997).

One of the aims in maintaining a sow herd should be to produce as many litters as possible between the second to fifth litters of a sow. These are the most productive litters, and they make the best use of farrowing facilities. Older sows tend to have large litter size but an increased number of stillbirths, more preweaning mortality, and lower weaning weights. In most herds the economically effective time to cull most sows is after they have had six litters, and only those sows that have had superlative litters should continue in the herd.

Nonetheless, many sows are culled before their sixth litter because of various problems such as infertility, poor legs, and poor mothering ability. These either increase the culling rate or force the producer to keep other sows above their sixth parity. Both these practices are counter-productive in providing sows to the farm in their most productive parities (Lucia, 1999; Lucia et al, 2000).

In herds with a high percentage of sows above the sixth parity, the culling rate may quickly be as high as 70% to 80%. This is counterproductive because high numbers of gilts' entering the farrowing room at the same time tends to increase problems with diseases such as preweaning diarrhea and pneumonia. It is much better to keep a consistent number of gilts going into the herd from year to year.

Evaluation of a culling program should include determination of the annual culling rate, average parity of females at culling, reasons for culling, and the interval from weaning or farrowing to culling (D'Allaire et al, 1987). The annual culling rate is defined as the number of females removed from the herd during the year divided by the average female inventory and multiplied by 100. The culling rate should include deaths, but they can be analyzed separately. A target annual culling rate of 39% (36% culling and 3% deaths) has been suggested. Comparisons of annual culling rates among

herds must take into account the inventory of gilts and sows. Gilts may be introduced into the inventory at different stages of their production cycle, which will have an effect on the culling rate if they are culled before or after they are bred. The culling rate is also influenced by other circumstances, such as a change in inventory, a change in culling policies, and the average length of lactation in the herd. There may be a sudden increase in culling rate if the producer suddenly realizes that the average age of the herd is increasing and begins to cull extensively in 1 year compared with a previous year. In the following year the culling rate may be down because a large proportion of the females are young. The average length of lactation for the herd may also influence the annual culling rate. Herds with short lactation periods tend to have a higher annual culling rate. This may be related to the increased probability of culling during each farrow-to-farrow interval; more farrowings per year lead to a higher annual probability of being culled.

Parity at Culling. Determination of the mean parity of sows at culling is the second step in evaluating the culling program. The average parity at culling varies from 2 to 4, but it can range from 2 to 8. Because the mean value can be influenced by extreme values, a parity distribution of culled sows is usually more informative.

Sows are culled when they are considered unsuitable for further production (D'Allaire et al, 1987). The reasons for culling can assist in identifying subclinical diseases or inadequacies in management. The most common reasons for culling, in order from highest to lowest frequency, are reproductive failure, old age, inadequate performance, locomotor disorders, and death and milking problems. In Denmark the likely causes of culling are leg weakness, problems related to farrowing and late pregnancy, disorders of the digestive system, disorders of the urinary system, and physical injuries. It has been mentioned that the proportion of disorders involving the gastrointestinal system has increased during the past 20 years (Christensen, 1997). Culling reasons can be analyzed according to two different rates: (1) the proportion of removals attributable to a specific reason (e.g., proportionate rate), and (2) a reason-specific annual culling rate. The proportionate rate is useful to indicate the relative importance of a given reason as part of total culling, and it helps in determining priorities for improvement in the herd. The reason-specific annual culling rate measures the risk of a sow being culled for that specific reason and indicates the extent of the problem. This is a more informative statistic, and it is not influenced by the number of sows culled for other reasons, as is the proportionate rate. Reason-specific annual culling rate is defined as the number of sows culled for a specific reason divided by the average female inventory.

Reasons for Culling. An investigation of culling patterns in 89 Minnesota swine breeding herds included 5918 sows and 1324 gilts for a total of 7242 culled females over a period of 12 consecutive months (D'Allaire et al, 1987). The definitions of the nine reasons for culling were as follows: reproductive failure included no observed puberty in gilts, no postweaning estrus, regular and irregular returns to estrus, negative pregnancy diagnosis, failure to farrow, and abortion. Inadequate performance included low numbers of pigs born alive or weaned, uneven litter, low piglet birth or weaning weight, and high preweaning mortality. Old age was a relative term and not defined clearly. Some producers culled sows as soon as the sixth or seventh parity and others only at the tenth. Locomotor problems included unsoundness, lameness, injury, abscess, downer-sow syndrome, and musculoskeletal disease. Death referred to an animal that died or was euthanized for humane reasons. Peripartum problems included dystocia; dead litter; metritis; prolapse of the vagina, uterus, or rectum; mastitis; and agalactia. Other diseases included those of all other body systems not included previously. Miscellaneous problems included the thin-sow syndrome, abnormal behavior, growth rate and carcass performance of market-pig progeny, abnormal piglets, market conditions, and no reasons. Transfer referred to an animal taken from the breeding herd and sold, leased, loaned, or given to another producer for breeding purposes.

Reproductive failure was the main reason for culling, varying from 20% to 50% of all removals. Failure to conceive accounted for 75% of all females culled for reproductive failure—80% for sows and 65% for gilts. Proportionally, culling as a result of anestrus was higher in gilts, accounting for 33% of all gilts culled for reproductive failure, which is twice as much as in sows. Culling for abortion accounted for only 4% of all those culled for reproductive failure. Inadequate performance accounted for 17% of all removals, and 70% of these sows had more than four litters. Old age accounted for 14% of all culls; the average age of these sows was 7.11 years. Death accounted for 12% of all removals and was the fourth most common reason for removal. Causes of death included the downer-sow syndrome, peripartum problems, difficult farrowings and prolapses, injuries, and various diseases. Locomotor diseases accounted for 9% of all removals. Peripartum diseases accounted for 7% of all removals. In general, the annual culling rate in these 89 herds was high, averaging 49%. The breeding life expectancy of sows was low at only 3.77 litters. The reasons for removal varied considerably among herds and among parities. Reproductive failure was of major importance, which indicates a need for increased awareness of the reproductive state of each breeding female at all times during the production cycle.

Lesions that could adversely affect production can be found in a large percentage of culled gilts and sows at slaughter. The prevalence of lesions of culled female swine at slaughter include foot lesions (59%), dermatitis (67%), and shoulder lesions (4.6%) (Ritter et al, 1999). Body condition scores were associated with the presence of dermatitis and shoulder lesions. Mean number of teats was 13.86 $\pm$ 0.02. Mean numbers of normal-appearing teats in the left and right rows were 6.57 $\pm$ 0.02 and 6.58 $\pm$ 0.02, respectively. Feet from 48% of the carcasses were condemned. Visceral lesions were present in 48.8% of the carcasses, of which 66% had liver spots and 43% had pneumonia. Knowledge of these lesions may assist in the health management programs in swine herds.

Environmental Factors and Culling. The relationships between management and environmental factors and annual sow culling rates in some swine herds have been examined (D'Allaire et al, 1989). With path-analysis techniques, only the type of flooring during gestation, the size of the herd, and the lactation length had a direct relationship with the annual culling rate. Producers' housing their sows in total confinement during gestation were most likely to keep them on partially or totally slatted floors, which were associated with a higher annual culling rate. Damaged slatted floors can increase foot and leg problems. Herds with an average weaning age of younger than 28 days were more likely to have a high annual culling rate. Sows kept in crates during the farrowing period were more likely to have a short lactation length, which was associated with a higher annual culling rate.

The relationships between other management and environmental factors and the annual culling rate were the result of common-cause associations. These factors included having the sows individually identified; using a more comprehensive recording system, mainly a hand-mating system; testing regularly for pregnancy; and housing sows in total confinement during the breeding period. Herds with more than 150 sows were more likely to have a high culling rate,

which may be a reflection of the various culling policies and the fact that managers and producers of large herds expect more productivity and better reproductive performance than those of smaller herds.

Criteria for Culling. The culling policy used has a major economic influence on the herd. Knowing when to cull a gilt or a sow that will be nonproductive is a major asset in ensuring continued high reproductive performance in the herd. The economics of culling strategies in swine herds has been examined using computer modelling to quantify the benefits of increased life span in herds and to optimize the decision to replace sows with poor reproductive and production performance (Dijkhuizen et al, 1986). The PorkCHOP computer program uses an index, known as the retention pay-off, that indicates the total extra profit that retention of a sow is expected to yield over her replacement, taking into account the risk of premature disposal. The index makes it possible to rank sows within the herd on potential future profitability and to know when to stop breeding if sows fail to conceive. The parity-specific default values that were used are considered typical of U.S. herds with continuous farrowing and standard management practices. They are as follows: an economic optimum herd life of 10 parities for average producing sows; an increase in income if the average parity at removal could be increased from 3.6 to 4.6; a significant financial loss per day of delay in conception; first-parity sows with a litter size of even 50% below average should not be culled on economic grounds; and average producing sows in the first, second, and third parity can fail to conceive at least three times before replacement becomes the more profitable alternative (Dijkhuizen et al, 1986). A comparison of the farmer's actual culling decisions and the computer model recommendations indicated that culling of older, poorly producing sows directly after weaning was the right decision economically. However, sows showing no heat were culled too early after weaning, and sows that failed to conceive were culled too late, from an economic standpoint (Dijkhuizen, 1989). Computer programs can now be used to assist producers in making economic culling decisions. It is expected that the computer will be of assistance to producers in making economic culling decisions.

Most purposeful culling occurs in sows from 3 and 5 years of age, when litter size begins to decline. Some criteria for culling include the following:

- Persistent anestrus in gilts older than 9 months of age. In some studies, up to 66% of gilts older than 9 months of age were culled for this reason.
- Persistent anestrus in sows lasting for more than 30 days after weaning.
- Failure to conceive after two successive matings.
- Chronic illness of any kind in which there is loss of appetite, persistent lameness, loss of body weight, and failure to respond to treatment.

CONTROL OF DISEASES OF THE PIGLET FROM BIRTH TO WEANING

An increase in the number of pigs produced per sow per year is a major means of improving efficiency of sow productivity. The number of pigs weaned per sow per year is a function of the number of piglets born alive and the number that survive to successful weaning. Preweaning mortality varies from 5% to 50%; in those herds with high levels of survivability, the producers are usually applying the principles of good management.

The basic requirements of the newborn piglet to ensure its survival and sound healthy growth are simple and well defined. Because both the number of pigs per litter in excess of sow nursing capacity and the occurrence of 15% to 20% of pigs with birth weights less than that needed for high percentage survival are common, management practices capable of supporting such piglets during the early postnatal period until weaning of the litter are essential. As the number of piglets born per litter increases, there is also an increase in the number of pigs that cannot be cared for well enough by the sow to ensure a concurrent increase in the number of piglets weaned per litter. By 3 or 4 days after delivery, each pig has selected a teat that it nurses exclusively, and therefore the maximum number of piglets reared by a sow is limited to the number of functional teats.

The factors that influence the number of pigs born alive, the number that survive to weaning, and their individual rate of gain include the process of parturition, the weight and vigor of the piglet at birth, the size of the litter, the parity of the sow, the lactation yield of the sow, the degree of warmth and comfort provided at birth, the adequacy of colostrum and milk, and the physical surroundings.

Birth weights within litters vary from less than 0.5 kg to more than 2.0 kg. Compared with heavier litter mates, low-birth-weight pigs often are born later in the birth order, take longer to first suck, and ingest smaller amounts of colostrum and milk. They are at a physical disadvantage in postnatal competition for available teats and frequently fail to achieve a regular and adequate suck. In addition, a greater surface area–to–body weight ratio combined with poor thermoregulatory control causes more rapid decreases in body temperature and, consequently, an increased risk of chilling, overlaying, and secondary infection. A strong positive correlation exists between birth weight, vigor, and neonatal survival. Under field conditions, preweaning survival rates of 25% to 45% are common in neonatal pigs weighing less than 907 g at birth. On the other hand, if low-birth-weight pigs are reared under optimum conditions, high survival rates are possible. In some surveys, birth weight was the most important determinant of a neonatal piglet's chance of survival (Gardner et al, 1989). Increases in birth weight category were associated with increasing odds of 7- and 21-day survival, with maximum survival obtained in the highest birth weight group, which consisted of pigs weighing more than 2 kg. Compared with piglets weighing less than 601 g at birth, for piglets weighing more than 2 kg at birth the odds ratio of survival was 349 (Gardner et al, 1989). In one large intensive piggery, of 238 litters born, 62% of all pigs with a birth weight of less than 800 g failed to reach weaning age. During the first few postnatal days, competition for nursing position is considerable, causing dissipation of energy and failure of adequate colostral and milk intake by many smaller pigs. In addition, average daily gain per piglet is highly variable among litters in the first and, to a lesser extent, the second week after birth, depending on the milk yield of the sow (Thompson and Fraser, 1988).

The sow is generally receptive to piglets other than her own, and she can, up to the limit of the number of functional teats, be used as a foster dam concurrently with or instead of nursing her natural litter. This attribute, to some extent, can adjust the inequity of number of piglets and number of functional teats, enhance the nutritional status and survivability of neonatal pigs, and increase sow efficiency. Early identification of litters with low initial gains might allow remedial action to be taken to reduce the problems of high mortality and low, variable gains later in lactation.

There is a 48-hour period in a pig's life when its odds of dying are up to one in three on some farms. It is the 48 hours after a sow begins to farrow a litter. Stillbirths and mortality during the first 2 days after farrowing can be added to create a rarely used statistic called *perinatal mortality* (PM).

Often PM can approach the one in three pigs born and, conversely, can be below 12%.

Infectious diseases are not usually a major contributor to perinatal mortality. Diseases caused by *E. coli* are usually controlled using sanitation and vaccines. A few diseases, such as pseudorabies and PRRS, may cause explosions of perinatal mortality, but rarely are their effects continuous.

There is often a sense of fatalism toward stillbirths and early mortality, with the attitude that "they were going to die anyway." This is usually not true, and although the solution is often not in a bottle of medication, there are distinct changes that can be made. The risk factors associated with high herds experiencing high perinatal mortality rates include the following:

- *Older sows.* In many genotypes, perinatal mortality may be higher in piglets born from sows in their fifth or greater parity. A common error is that sows are replaced one parity too late, when problems occur, rather than earlier, since perinatal mortality is usually predictable in older sows. An alternative strategy is to plan and schedule earlier replacement of stock, ensuring good replacement gilts are available.
- *Body condition of sows.* Fat sows have more problems in farrowing and lactation, leading to a higher incidence of perinatal mortality in their litters. Veterinarians can assist producers in monitoring the body condition scores and nutritional needs of pregnant sows.
- *Ambient temperature in farrowing crate.* Newborn piglets are quickly affected by chilling at birth. Lightweight piglets are susceptible to chilling and are often the "runts" that are found moribund in the corner of the farrowing crate in the morning. Chilling is prevented by using extra heat sources in the farrowing crate. One common method is to place two heat lamps on either side at the rear of the crate when the sow is farrowing unattended.
- *Care of newborn piglets.* Perinatal mortality rates can be reduced by taking the time to attend to details such as aiding in farrowing, removing fetal membranes from the noses of piglets, placing piglets near a teat, and cross-fostering. This demands either a large amount of time or the use of induced farrowing, which helps to synchronize and schedule farrowings so that assistance at farrowing can be provided.
- *Colostral intake.* If there are outbreaks of systemic infections such as coliform septicemic, there is a need to reexamine the handling of piglets at birth to ensure immunological competence. It is often useful to ensure colostral intake by manually extracting colostrum and feeding it to the piglets.
- *Infectious disease control.* Herds with inadequate attention to an AIAO farrowing cycle, inadequate sanitation and cleaning and washing of farrowing crates between sows have a higher incidence of acute infectious diarrhea in the piglets.

Magnitude and Causes of Preweaning Morbidity and Mortality

Morbidity and Mortality Data

On a worldwide basis preweaning losses range from 15% to 25% of piglets born alive.

More than 50% of preweaning losses occur during the perinatal period from birth to 3 days of age. The perinatal mortality rate is influenced by litter size, the age of the sow, the type of confinement of the pregnant sows, and the degree to which the farrowing is attended.

The NAHMS National Swine Survey in 1990 found that the most common cause of preweaning morbidity was acute undifferentiated diarrhea (42%) most of which occurred during the first 3 days of life (Tubbs et al, 1993). Management factors are responsible for the majority of preweaning piglet morbidity and mortality in the United States. The most common causes of mortality were trauma (43%), starvation (20%), unknown causes (13%), and diarrhea (10.8%).

A survey of perinatal mortality in 48 North American swine herds found that 6.8% of piglets were stillborn (Vaillancourt et al, 1994). Of piglets born alive, 3.9% died within 24 hours of birth. The highest perinatal mortality rates occurred in very small litters (less than 4 piglets) and very large litters (more than 17 piglets). Perinatal deaths increased as parity increased. The highest mortality percentage was recorded on Monday, which may be due to the recording of Sunday deaths on Monday. Over half of all perinatal mortality (51%) was attributed to only 13.2% of the litters, which supports earlier observations that 75% of all stillbirths occurred in only 25% of litters. It has also been observed that over 50% of stillborn piglets are from litters that had two or more stillborn piglets.

Risk Factors

The association between preweaning mortality and various facility factors was examined as part of a NAHMS survey (Yeske et al, 1994). Significant associations were found between preweaning mortality and flooring type, heat source, water delivery system, cleaning frequency, cleaning method, and duration of idle time between farrowing groups. Concrete floors are associated with an increased morbidity and mortality from diarrhea; wire floors are superior. A creep heat source such as heat lamps or radiant heat is considered better than under-floor heating. Longer idle times between farrowing and the cleaning of the farrowing area after every farrowing is recommended. In a survey of the management variables associated with reduced preweaning piglet mortality, those that reduce the exposure of suckling piglets to the pathogens of older pigs or previous occupants of the farrowing facilities were considered most effective (Bowman et al, 1996). In the same survey, there was no significant reduction in preweaning mortality associated with prefarrowing vaccination and the use of anthelmintics or insecticides, supplemental milk, or iron.

Causes of Mortality

The losses caused by crushing of the piglet by the dam and other fatal traumatic lesions constitute the largest mortality group among live-born pigs in most herds and contribute significantly to noninfectious losses. An average of 5% to 6% of live-born pigs die from traumatic injuries (Svendsen et al, 1986). Mortality caused by traumatic injuries varies greatly from herd to herd, and it is apparent that these losses are related to a large extent to housing systems and husbandry routines. During a 5-year study of the preweaning mortality in a Swedish Landrace herd of 100 sows, the distribution of deaths according to age was as follows: antepartum (14%), intrapartum (16%), day of birth (16%), Day 1 (15%), Day 2 (13%), Days 3 through 6 (12%), and Days 7 through 34 (14%). The causes of death and their percentages were as follows: antepartum (14%), intrapartum (16%), traumatized (22%), weak and undersized (11%); splayleg and splayweak (12%), starvation (4%), malformations and miscellaneous causes (6%), and infectious diseases (15%). Most traumatic injuries and risk situations, irrespective of the type of farrowing accommodation, occur within the first 24 to 36 hours after birth. Most traumatic injuries occur when the sow moves when standing up or lying down and when standing or walking. Most of these injuries are caused by the hindquarters and the hindlegs of the sow; therefore

30% of all traumatic injuries occur around the sow-feeding times in the morning and afternoon.

Starvation, crushing by the sow, and *stillbirths* were the three main causes of preweaning mortality in a Canadian study of 2388 piglets born over the second to fourth parity in 124 Yorkshire and 109 Yorkshire-by-Lacombe sow litters. The failure of piglets to obtain an adequate milk supply within a few days of birth, either as a result of agalactia or competition with larger and stronger piglets in the litter, was the primary factor contributing to piglet death and may account for in excess of 85% of the losses (Dyck and Swierstra, 1987). These losses can be minimized by cross-fostering of piglets shortly after parturition to equalize litter size and to reduce variation in piglet weight within the cross-fostered litter, or by artificial rearing of ill-thriving piglets and piglets from litters whose sow dies. Such practices can increase piglet survival to 95% of the piglets born alive. In a study of preweaning mortality in Ontario farrow-finish pig farms, stockmanship was an important modifier of environmental effects that were associated with mortality.

Information on neonatal piglet mortality in the United Kingdom reveals that the majority of losses occur by the end of the second day after birth. Mortality increased as litter size and the age of the sow increased and as birth weight decreased. In one study, five groups of primary factors were found to contribute to 88% of the deaths of 236 live-born piglets from one herd.

An analysis of piglet morality in a breeding herd kept outdoors in the United Kingdom found that, during a period of 8 months, the majority of deaths (72%) had occurred by the time the litter was first inspected, 27% of these piglets had uninflated lungs, and 53% of the piglets born alive had no food in their stomachs (Edwards et al, 1994). Of the stillborn pigs 17% were of Type I (events before birth) and 83% were of Type II (events after birth). At all ages crushing was the most common cause of death (72%) of liveborn piglets.

The timing and causes of piglet mortality have been examined in alternative and conventional farrowing systems (Marchant et al, 2000). In communal farrowing pens, sows were allowed to move freely and in the conventional crates they were restricted. More piglets were weaned from the conventional crates than from the open systems and the piglets grew more quickly. In the two open systems, 17% and 14% of the piglets born alive were crushed, compared with only 8% in the crates. Monitoring of sows and litters in detail in a communal pen system found that during the first 7 days, 75% of the liveborn mortality was due to crushing. The total of piglets dying per litter, including stillbirths, was significantly associated with the total litter size and the sow's parity. The percentage liveborn mortality was significantly associated with the parity and body length of the sows and with the within-litter variation in the birth weight of the piglets. Individual birth weight was closely associated with percentage survival. Only 28% of piglets weighing less than 1.1 kg at birth survived to 7 days of age. The alternative systems used in the experiments may have enabled the sow to express a greater range of maternal behavior, but only to the severe detriment of the welfare of the piglets. Piglet mortality was much higher than in conventional farrowing crates, and crushing in the open system was a major problem.

Infectious Diarrheas. The infectious diarrheas of newborn piglets are among the most common causes of preweaning mortality with mean incidence rates varying up to 50% (Svensmark et al, 1989a,b,c,d). However, the incidence of preweaning diarrhea in piglets continues to decrease. Some of this decrease is a result of recording criteria, but management factors have a major influence. Large, intensively managed herds now have a high level of hygiene, and the entire production system is under close, continuous control, including the use of supplemental iron and vaccination, especially for *E. coli* (Dewey et al, 1995c). The factors that affect the incidence of diarrhea in nursing piglets include the parity of the sow, the occurrence of the MMA complex in the sow, the litter size, the herd size, and the gilt proportion in the herd. In Danish swine herds, in addition to the diarrheas caused by enterotoxigenic *E. coli* and *Isospora suis,* rotavirus is considered to be a significant cause of diarrhea in piglets from 3 to 5 weeks of age. The type of mild diarrhea in 3-week old pigs known as steatorrhea or white scours may be associated with rotavirus infection, possibly in combination with *E. coli* and other agents (Svensmark et al, 1989c). In addition, litters that shed rotavirus during the suckling period had lower weight gains and higher incidence rates of respiratory diseases than virus-free litters. It is also suggested that piglets should not be weaned before either 3 weeks of age or a body weight of 6 to 7 kg has been reached.

During the first 3 days of life, enterotoxigenic *E. coli* is the most common causative agent associated with diarrhea in piglets. From 4 to 14 days of age, piglet diarrhea may be associated with various enteric pathogens. The common ones are the TGE virus, *I. suis,* and *C. perfringens* type C. Less common ones include other porcine coronaviruses, strongyloides, and, rarely, *Serpulina hyodysenteriae.*

The herd and litter level factors associated with morbidity and mortality resulting from diarrhea in piglets 1 to 3 days of age was examined in 29,843 litters from 708 herds monitored for production (Wittum et al, 1995). The average rate of diarrhea morbidity among 1- to 3-day-old piglets was approximately one new case/day in a herd with an inventory of 100 piglets. Diarrhea mortality averaged approximately one death every 10 days for the same size of herd. Both diarrhea morbidity and mortality were lower in herds that vaccinated sows against *E. coli.* The risk of diarrhea morbidity and mortality was higher among litters in which the sow experienced health problems within 3 days of farrowing. This suggests that the use of *E. coli* vaccines, along with careful observation of the postpartum sow for evidence of clinical disease, crossfostering piglets, and appropriate treatment, might reduce the occurrence of diarrhea in piglets from 1 to 3 days of age.

The herd and litter level factors associated with the morbidity and mortality resulting from diarrhea in piglets 4 to 14 days of age were examined in 29,843 litters from 708 herds (Dewey et al, 1995c). Diarrhea increased with herd size, sow health problems, deworming sows in the farrowing crate, and routine use of supplemental milk for piglets. Diarrhea decreased with AIAO farrowing rooms, washing of sows, TGE-free herd status, and vaccination of sows against *E. coli.* Diarrhea mortality increased with litter size, sow health problems, fostering of piglets at 4 to 14 days of age, and sow mange-lice treatment while in the farrowing crate. Diarrhea mortality decreased with fostering of piglets out of the litter at 1 to 3 days of age, use of supplemental iron, use of a hired manager in the farrowing facility, and *E. coli* vaccination. The factors not associated with diarrhea morbidity and mortality included vaccination of piglets, clipping of teeth, docking of tails, antibiotics fed to the sow, farrowing problems, operation type, supplemental creep feed, vaccination of sows against TGE or rotavirus, treatment of navels, facility type, and use of a consultant such as a veterinarian, nutritionist, or extension agent. Vaccination of sows for *E. coli* and fostering of piglets off sick sows are expected to decrease preweaning losses resulting from diarrhea in 4- to 14-day-old pigs.

Vaccination of pregnant sows against enterotoxigenic *E. coli* is effective in reducing morbidity and mortality resulting

from diarrhea in neonatal piglets (Wittum and Dewey, 1996). A partial budget analysis of vaccination of sows found that the swine producer who does not currently vaccinate sows against *E. coli* could expect to generate $5.51/sow in additional yearly profits by implementing a vaccination program. Losses attributable to piglet diarrhea would be reduced by nearly $10/sow/year. Investment in a sow *E. coli* vaccination program would expect to result in a 124% return on investment. Threshold analysis found that herd with diarrhea morbidity and mortality rates in 1- to 14-day-old piglets of at least 3.5% and 0.8%, respectively, could expect returns adequate to justify investment.

Hemorrhagic necrotic enteritis in piglets is caused by *C. perfringens* types C and A; although type C is most common (Songer and Glock, 1998). Type C infections can usually be controlled by vaccinating sows with a toxoid. The organism is susceptible to antibiotics, and prophylaxis of type C infections has been achieved by the use of feed grade bacitracin at 250 g/ton of feed, from 2 weeks prefarrowing and followed through lactation.

TGE in nursing pigs is characterized by high morbidity and mortality resulting from diarrhea. Clinical management of outbreaks requires implementation of a strict AIAO movement of pigs (especially in the nursery rooms), enhancing the immunity of pregnant animals by vaccination, improving the cleaning and washing activities of the farrowing and nursery rooms, and considering a partial depopulation protocol (Carpenter and Templeton, 1996). In Britain, serological evidence suggests that infection is widespread (Pritchard et al, 1999).

Porcine epidemic diarrhea is caused by a coronavirus CV777. Porcine epidemic diarrhea type I causes diarrhea and anorexia in adult pigs, and porcine epidemic diarrhea type II causes diarrhea in unweaned pigs (Pritchard et al, 1999). Herd outbreaks of porcine epidemic diarrhea can occur in finishing pigs and the disease is clinically indistinguishable from TGE.

Coccidiosis in nursing piglets is caused by *I. suis* and is characterized by a non-hemorrhagic diarrhea with low mortality. Experimentally, piglets inoculated with *I. suis* at 3 days of age develop more severe clinical disease than do older piglets (Koudela and Kucerova, 1999). Control depends on improved sanitation and chemotherapy with coccidiostats.

Staphylococcus hyicus (greasy pig disease, exudative epidermitis) is a bacterial infection of newborn piglets under 1 week of age that enters through skin wound, causing necrosis and exudation of serum. The skin becomes reddened then thickened, then brown with serum exudate, and finally brown and crusty. Death can occur within 2 to 3 days, but most affected pigs just have reduced growth rates. Prevention is through control of initiating factors. Treatment is by injectable antibiotics (most are efficacious) or by topical treatment with a mild disinfectant.

Control of Preweaning Mortality

Colostrum and Colostral Immunoglobulins

The newborn piglet requires an adequate intake of colostrum within a few hours after birth, a continued daily intake of milk, a warm environment of 30° to 34° C for at least the first 3 days of life, and protection from traumatic injuries such as crushing by the sow. Every economical effort must be made during the first 3 days of life to provide an optimum environment that will minimize crushing, chilling, starvation, and infectious disease.

The acquisition of an adequate level of colostral immunoglobulins is of vital importance. Some surveys indicate that piglets that fail to survive absorb only 10% to 50% as much immunoglobulin in the first 12 hours after birth as their age-matched surviving controls. Several factors can affect the levels of serum immunoglobulins achieved in the newborn piglet by 24 to 48 hours after birth. The concentration of immunoglobulins in the colostrum may vary from one sow to another by a factor of 10. The parity of the sow, the kind of feed used, the type of farming, the number of sows raised on the farm, and the level of management may affect the concentration of immunoglobulins in the colostrum of the sow.

Any factor that interferes with the movement of the piglet from its birthplace to the mammary gland will affect the time when the animal begins to suck colostrum and the amount that it ingests. The feet of the piglet may become stuck in a perforated floor in which the holes are too large, or solid floors may be too slippery and the piglet may become crushed by movements of the sow. The sow may refuse to allow the piglets to suck because of sow hysteria, agalactia, or other illness. Generalized weakness of the piglet may not allow it to compete successfully for a nipple during sucking. Exposure to cold may affect the amount of colostrum ingested by newborn piglets. Piglets are kept at an ambient temperature of 18° to 20° C.

The behavior of the sow and the piglets affects the amount of colostrum the piglets consume. The way the sow exposes her udder, the competition at the udder (especially in litters with large variation in birth weight), and the development of synchronized behavior in the piglets and in sow vocalization are all important features (Castren et al, 1989; De Passille and Rushen, 1989). The strategies of teat-seeking behavior of neonatal piglets and directing the teat-seeking behavior of piglets by farrowing crate design have been examined (Rohde and Gonyou, 1987; Parfet and Gonyou, 1990). Certain experimental designs of farrowing crates are being examined for their effectiveness in directing piglet movement and increasing the speed of movement from the posterior of the sow after birth to the udder.

The transfer of passive immunity to piglets from colostral immunoglobulins is essential to piglet survival in two ways: (1) during the first 24 hr of life, IgG and IgM, the major immunoglobulins of sow's colostrum, are absorbed directly from colostrum, providing systemic protection against infection, and (2) immunoglobulins in milk provide local protection (e.g., lactogenic immunity) in the small intestine until weaning. There are large individual animal variations in the concentrations of colostral immunoglobulins IgG, IgM, and IgA in the lacteal secretions of sows; most of these variations are associated with stage of lactation rather than any single physiological factor (Klobasa and Butler, 1987). Individual variation seems to be the largest influence. There is a rapid decrease in total Ig concentration during the first day after birth (e.g., 3.4%/hr), which means that it is possible that pigs born at the end of a prolonged parturition obtain colostrum with a lower Ig concentration at their first suck than that encountered by their earlier-born litter mates. However, this may only be a factor if pigs are born too weak to suck or are prevented from doing so by stronger pigs, because there is no difference in the serum concentration of maternal Ig between pigs sucking for the first time 4 hours after parturition than in those sucking immediately after birth. Much of the difference in IgG levels may result from differences between sows for colostrum produced at the time of farrowing. These sows may also have lower milk production. The behavior of the piglets can influence their IgG levels relative to those of litter mates. However, this effect is small; birth order, number of teats sucked, and the frequency of sucking bouts account for only a small proportion of the variation in IgG levels within litters. The changes in the concentrations of serum IgG, IgA, and IgM of sows throughout the reproductive cycle can be divided into four phases.

The major immunoglobulin component of sow milk is secretory immunoglobulin SIgA, which is synthesized locally within the mammary gland and forms a continuous defense, protecting the nursing piglet from disease caused by enteric pathogens (Salmon, 1989). This local protection provided by milk, in contrast to the systemic protection provided by colostrum, is called lactogenic immunity (Salmon, 1989). Most of the immunoglobulin in the milk of the sow is thought to originate from the immune system of the intestinal tract (Salmon, 1989).

There has been much interest in the routes of immunization of sows that will provide the optimum level of colostral and milk immunoglobulins for protection of piglets against the common systemic and enteric infections. The parenteral immunization of pregnant sows with diffusible antigens causes a systemic humoral immune response and the production of IgG and IgM. Stimulation of the immune system of the gut of young pigs will result in the production of intestinal IgA, which can protect weaned pigs from infectious enteric disease. In the sow, stimulation of the intestinal tract by oral vaccination will cause the production of both IgM and IgA. The IgA is transferred to the mammary gland and into the milk; this is known as the gut-mammary axis.

Preweaning Mortality Risk Factors

Several risk factors have been associated with preweaning piglet mortality.

Size of Litters. Large litters (e.g., over 12) are associated with undersized piglets, which are weak and more susceptible to crushing and starvation than heavier piglets. Mortality is usually higher in piglets born from sows that have had eight or more litters. Also, litters from large conventional herds or from herds with a high stocking density are expected to have a high risk of acquiring lameness in piglets. Mortality is also occasionally high in piglets born from gilts because of sow hysteria. There is also considerable variation in mortality rates between herds, which is probably a reflection of the level of management. The most significant variables associated with mortality are the use of AIAO pig flow in farrowing house and washing sows before farrowing. Other management variables that tended to reduce mortality are oxytocin injections, deworming, and vaccination for TGE, rotavirus, and erysipelas (Bowman et al, 1996).

Supervision at Farrowing. Because perinatal mortality (e.g., from birth to 3 days of age) accounts for approximately 60% of preweaning piglet mortality, the level of management and supervision at farrowing time and the quality and the environment of the facilities assume major importance. The frequency of stillbirths can be reduced by allowing sows in late pregnancy some daily exercise and by attendance at the time of farrowing to assist pigs that are hypoxemic and may be covered by placenta. Farrowing may be induced and synchronized to occur at a time during the day or week when maximum supervision is available. Piglets from large litters can be cross-fostered most successfully when done as soon after birth as possible to ensure one functional teat per piglet, thus securing sufficient colostrum for each suckling pig in the litter.

Infectious Disease Control. The common infectious diseases of newborn piglets can be controlled by a combination of batch-farrowing; regular cleaning and disinfection of the farrowing crates between sows; a closed-herd policy, which minimizes the introduction of infectious agents through carrier breeding stock; and vaccination of pregnant sows to stimulate the production of specific antibodies to transfer to the newborn through colostrum. The early recognition and treatment of postparturient diseases of the sow are also indicated to prevent the spread of infectious diseases to the piglets and to minimize starvation and hypoglycemia resulting from agalactia.

Drinking Water for Piglets. The provision of drinking water to newborn piglets is controversial. Piglets drink appreciable amounts of water on the first days after birth, especially if their milk intake is limited. Water use varies among litters, with an average of 46 ml/piglet over the first 4 days. It has been speculated that undernourished piglets, especially those housed in a warm environment, may be prone to dehydration in the first few days after farrowing. Water intake may help to prevent dehydration and to promote survival of piglets with low early milk intake.

Supplemental Heat for Piglets. An important environmental requirement of the piglet from birth to 3 days of age is supplemental heat to prevent chilling. This is usually provided most effectively and economically with heat lamps. The lower critical temperature of the newborn piglet is estimated to be about 34° C, and the highest proportion of piglet death loss as a result of chilling occurs during the first 72 hours after birth. In draft-free farrowing units with an ambient temperature of at least 21° C, the provision of supplemental heat beyond 3 days of age is usually not necessary. Supplemental heat from 3 to 21 days of age improves rate of gain compared with piglets with no supplemental heat, but it is not economically advantageous under ideal management conditions.

Low Birth Weight. The causes of low birth weight in piglets are difficult to identify retrospectively. It is not unusual to find litter mates differing by as much as 200% in body weight at birth. Possible influences on birth weight include maternal factors such as size of placental development in early gestation and the effect of nutrition on the sow during pregnancy. However, it is not yet possible to achieve uniformity in birth weight through feeding or by selection.

The most effective method to achieve uniformity in birth weight within litters is to batch-farrow and cross-foster piglets between simultaneously farrowed litters so that all the small piglets are allocated to one sow and the larger ones to another sow. Also, cross-fostering during the first few days of life is an effective method of accommodating the variation in rearing capacities of different sows. Rearing capacity is determined by the number of functional teats that are adequately exposed to the piglets in the crucial first days of life. Piglets in excess of the number of functional, exposed teats are transferred to sows with spare capacity. Cross-fostering should take place within 6 hours of farrowing for maximum benefit. Cross-fostering is used in 98% of commercial swine herds in the Midwestern United States and in Canada (Straw et al, 1998). Across all farms, a mean of 8.6% of piglets are cross-fostered.

Routine Procedures. Procedures that are performed routinely in piglets from birth to weaning at 3 weeks of age include clipping needle teeth after birth; docking tails at 2 to 3 days of age to prevent tail-biting; administration of iron dextran; castration at 3 to 5 days of age or at 10 to 14 days of age; providing creep-feed at 7 to 10 days of age, with increasing amounts up to weaning time; providing a water supply; and applying a method of identification of the litter or individual pigs. Castration performed at 3 days of age interferes with growth rate compared with castration at 10 days of age, but the difference is not significant at weaning (Kielly et al, 1999). Records should be kept of the birth date, the number of pigs born alive and dead, and the number of pigs that were treated and that died during the nursing period. If possible, necropsies should be done on each dead pig and the information recorded.

Farrowing Crate Design. As a result of the Swedish studies described in the "Causes of Mortality" section, a special unit for farrowing and neonatal pigs (the nursery unit) has evolved. Nursery units are constructed so that the stockperson has easy access to the piglets, and a local temperature close to the critical temperature of the newborn pig can be provided

(Svendsen et al, 1986). The unit has a room temperature of 22° C, and the sow, maintained in a farrowing crate, is kept on a totally perforated floor without straw bedding. The farrowing crates are clean and well insulated and have moveable heat lamps placed over the piglets parallel to the udder of the sow. The location of the heat lamps defines the location of the creep areas. This design minimizes the chances of piglets becoming chilled, which reduces the occurrence of traumatic injuries. This type of unit can be used with group farrowings, in which the sows are moved into the unit 2 to 3 days before farrowing and remain there for a period of no longer than 1 week after farrowing, at which time they can be moved to a more conventional type of accommodation.

The eliminative behavior of piglets should also be considered when designing the creep areas of farrowing crates. "Swine are probably the cleanest and most orderly of the farm animals when circumstances permit the expression of their normal patterns of elimination" (Whatson, 1985). Piglets do not eliminate where they sleep, nor do they lie where they eliminate. Neither the sow nor the siblings play a role in influencing where a piglet eliminates. Because there is no evidence that piglets have a preferred site of elimination but rather do not eliminate where they lie, it is not possible to predict where a piglet will eliminate based on where it last eliminated.

Prevention of Traumatic Injuries. The incidence of traumatic injuries to newborn piglets can be reduced by using farrowing crates designed to prevent the sow from lying down in one motion, and by the surveillance of sows to ensure that any evidence of sow hysteria, sow aggressiveness, and other illnesses of the farrowing sow are recognized and treated accordingly. Comparative behavior and production studies have shown that there are five main factors that are important for reducing losses resulting from traumatic injuries.

Fixation of the Sow. Farrowing crates require special design of the sides, which direct the movement of the sow when she lays down, and make possible the adjustment of the crate to the size of the sow and her litter. This type of rigid fixation is necessary for only the first few days after farrowing.

Flooring. The nature of the flooring should permit the sow to control the speed of her descent as she lays down and that provides a well-insulated, clean, comfortable, nonslippery surface for the piglet to reduce the occurrence of traumatic injuries. If straw bedding is used, the straw should be chopped into small pieces of about 1 in or less, so the piglets can easily push them out of the way when escaping from their dam.

Husbandry Routines. The litter from the area of the sow should be removed at sow feeding and dunging-out times during the first 2 to 3 days after farrowing. Group farrowing, which permits the adjustment of litter size and more intensive monitoring of the litters during the crucial 2 days after farrowing, contributes to a reduction in losses but will also increase the work of the attendants. Therefore the provision of a good working environment with low box walls and easy access to the sow and piglets is a necessity.

HEALTH MANAGEMENT AND PRODUCTION OF THE WEANED PIG

After weaning at 3 to 5 weeks of age and at 5 to 7 kg, the piglets are reared in groups in weaning or nursery pens until they are about 10 to 12 weeks of age weighing 20 to 25 kg. From the nursery pens they are moved into the growing and finishing pens. Major advances in the science of nutrition of the weaned pigs and our understanding of the pathogenesis of enteric disease of pigs have made it possible to wean pigs successfully and to control diseases such as postweaning diarrhea.

The weaning process and postweaning performance are the most critical events of a pig's life, secondary only to the problems associated with survival in the first few days of life. When pigs are weaned, they are stressed by the environmental, nutritional, and social changes to which they are exposed. Therefore every economical effort must be made to make the transition from the dam to the weaning pen as smooth as possible. This requires attention to the management of nutrition, housing, sanitation, and hygiene, as well as measurement of actual performance, including weight gain and feed efficiency.

The common diseases or causes of suboptimum performance that may cause high morbidity and significant economic loss within a few weeks after weaning are as follows:

- Postweaning multisystemic wasting syndrome *(Circovirus)* (Harding et al, 1998)
- Postweaning decrease in body weight gain, identified by postweaning check
- Coliform gastroenteritis, also known as postweaning *E. coli* diarrhea
- Postweaning diarrhea caused by porcine rotavirus
- Swine dysentery *(Brachspira hyodysenteriae)*
- Meningitis and septicemia caused by *S. suis* (MacInnes and Desrosiers, 1999)
- Ascariasis *(Ascaris suis)*
- Bacterial respiratory diseases:
  Bordetella bronchiseptica (rhinitis and pneumonia)
  P. multocida (pneumonia)
  M. hyopneumoniae (pneumonia)

Less common diseases that usually occur sporadically are as follows:

- Intestinal adenomatosis complex (*Lawsonia intracellularis)*
- Pityriasis rosea
- *H. parasuis*

The factors and procedures that are important for optimum health and production of the weaned pig are as follows:

- Optimum age at weaning and postweaning growth performance
- Method of weaning and mixing litters and control of agonistic behavior and behavioral vices
- Nutrition of the weaned pig
- Maintenance of systemic and intestinal immunity
- Therapeutic and subtherapeutic use of antimicrobials
- Housing and environment (the nursery)

Postweaning mortality from weaning to the beginning of the growing-finishing period ranges from 0.5% to 8.0% and may be higher. With good management the mortality rate can be kept down to 1% to 3%.

Optimum Age at Weaning and Postweaning Growth Performance

Under commercial conditions, the optimum age for weaning is between 3 and 4 weeks of age. Weaning at this age causes optimum subsequent reproductive performance of the sow. Weaning at an earlier age would not increase the number of litters per sow per year, because sows do not usually return to estrus until 30 days after farrowing. Early weaning at 2 to 3 weeks of age may also decrease cellular immunity compared with pigs weaned at 5 weeks of age.

The behavior of pigs weaned at 12 and 21 days of age from weaning to market has been examined experimentally (Gonyou et al, 1998). During the subsequent 48 hours, pigs weaned at 21 days of age spent more time eating than those weaned at 12 days of age. During the subsequent 6 weeks, pigs weaned at 12 days of age spent more time eating, drinking, nosing other pigs, and chewing on objects than did those weaned at 21 days of age. The delay in eating and the higher incidence of anomalous behaviors by earlier weaned pigs suggest that additional improvements in early weaning management are desirable.

Between 3 and 10 weeks of age, the average daily gain of weaned piglets fed an appropriate weaner ration under good management and adequate housing reaches 400 to 500 g/day. Postweaning performance can be increased by using complex diets containing several different energy and protein sources, but these diets are also more expensive and the increased gain may not always be economical.

The growth rate of pigs during the postweaning period should be monitored weekly, if possible. A practical method for weighing pigs on a weekly basis is not yet available, but performance must nevertheless be monitored if optimum performance is to be achieved.

Method of Weaning and Mixing Litters and Control of Agonistic Behavior and Behavioral Vices

The procedure of weaning should be performed with the least stress possible to the pigs. There are various ways to wean pigs. Some producers use split-litter techniques; some wean and group pigs by size. Under ideal conditions, the litters that are to be combined and moved into a weaner pen should be allowed to mix together before they are weaned. This is done by removing the partitions between the farrowing crates and allowing the litters to mix for 2 to 3 days before weaning. At weaning, the sows are removed, and the piglets are left in the farrowing crates for an additional few days. Familiar surroundings encourage the piglets to eat the dry feed and to drink water. Two to four litters then may be placed together in a weaner pen that has been cleaned previously, left vacant for a few days, and equipped with a fresh supply of feed and water. The entire group should be weighed when placed in the pen and again when moved out, and the amount of feed used in each pen recorded for determination of feed efficiency.

A common practice is to remove the sow and the piglets from the farrowing crate on the day of weaning and to place the piglets in the weaning pens immediately. When piglets from different litters are mixed in weaning pens, they fight to establish a new hierarchical dominance order. The introduction to a new environment and the separation from their own sows constitute severe stressors, which lead to elevated levels of circulating corticosteroids, depression of the immune system, and secretion of catecholamine.

The literature describing aggressive and agonistic interactions between domestic pigs has been reviewed (Petherick and Blackshaw, 1986). When unacquainted pigs are mixed together they display agonistic behaviors, which is a continuum of behaviors expressed in conflict situations and includes offense, defense, and submissive or escape components. The behavior may include contact, such as biting and pushing, or noncontact, such as threats in the form of body postures and gestures (Petherick and Blackshaw, 1986). Aggressive behavior is a component of agonistic behavior. Contact behaviors and threats are offensive in nature and are termed aggressive behaviors. These behaviors are also called fighting.

Tail biting, ear biting, ear chewing and ear sucking, belly rubbing, and fighting are all described as behavioral vices when observed in groups of pigs. When outbreaks of these vices occur, productivity may be markedly reduced. Tail biting can cause systemic infection and incurable abscesses. Poor ventilation, faulty nutrition, overcrowding, and boredom are among the suspected predisposing factors. However, there is no clear explanation of the etiology. Some observations suggest that behavioral vices could develop from the normal nosing behavior of pigs maintaining their hierarchy. Piglets still desiring oral stimulation may be rewarded by touching pig flesh. Presenting of pigs with a textured, mobile surface that provides stimulation to the sensitive nose and mouth region after weaning but before behavioral vices occur may prevent unsatisfied feeding behavior from being redirected toward other pigs. Attention to the environment, stocking rate, feed and water space, and the removal of particularly aggressive pigs also help to control the problem.

Over the first 6 weeks after birth, the main behavioral change in pigs consists of an increase in overall activity and in behavior associated with the ingestion of solid feed: feeding, drinking, rooting, and defecating.

During the first few days after weaning, there is a sudden increase in general activity and aggression, coupled with restless behavior when the animals lie down together. Pawing the floor is also common and may be a form of nest building for comfort. There is also a very rapid increase in feeding behavior during the first day after weaning, with a much slower rise in the frequency of defecation. It has been suggested that perhaps the combination of restless activity, the difficulty of lying together, and the stress of physiological adaptation to the new diet may lead to a state of fatigue and predispose to infectious diseases, which are common in the recently weaned pig. The importance of a consistently high ambient temperature for the early-weaned piglet is also recognized and may be a factor in postweaning behavior.

The mixing of unfamiliar pigs leads to aggressive interactions, which can result in wounds that may become infected. The effect of mixing on growth rate and feed efficiency has been contradictory (Petherick and Blackshaw, 1986). Mixing also causes increased competition for feed if feeding space is restricted, and the adverse effects of competition can be minimized by ad libitum feeding, providing barriers between pigs, and having regular feeding times. Competition for space may also result in aggression.

If aggressive behavior among pigs is minimized, the welfare and production of the pigs are improved. Aggression can be reduced by keeping the mixing of unfamiliar animals to a minimum. When unfamiliar pigs must be mixed, elimination of competition for resources such as feed and floor space helps to reduce aggression (Petherick and Blackshaw, 1986). Tranquilizers appear to be effective in reducing aggression, but they are expensive and impractical to use on a regular basis.

The effect of the method of weaning on the behavior of the sow has been examined (De Passile and Robert, 1989). During the 4 hours after weaning, sows may be more active and restless if they are moved away from their piglets to a different pen than if the piglets are moved away and the sow remains in the farrowing crate. The significance of these findings must be evaluated.

Swine producers should be encouraged to weigh pigs in and out of the weaner pens on a regular basis. This provides an excellent record of performance that can be evaluated; action can be taken when there is suboptimum performance. Producers are initially reluctant to weigh weaner pigs, but after seeing the results of a few batches, they commonly recognize the benefits of such a practice.

Nutrition of the Weaned Pig

Transition at Weaning

A major problem of early weaning at 3 weeks of age has been the nutrition of the weaner pig. At 3 weeks of age the piglet is still heavily dependent on sow's milk, which is highly digestible, and the digestive enzyme capacity of the piglet at this age is just beginning to adapt to digestion of nonmilk proteins and carbohydrates. Therefore a suddenly change in the diet of the nursing piglet at 3 weeks of age from sow's milk to a cereal-based diet without a period of

adjustment is an additional stressor. Sudden change in diet commonly causes an obvious depression in the rate of gain called the postweaning growth check. The postweaning growth check lasts from 7 to 14 days, depending on managerial and environmental factors, and it is characterized by little or no weight gain and low feed intake, frequently accompanied by diarrhea. The poor weight gains are largely a reflection of low feed intake and are not the result of inefficient feed conversion.

Early weaned pigs placed in an unfamiliar environment and offered an unfamiliar source of feed may not consume an amount sufficient to meet maintenance requirements (Bark et al, 1986). The reduction in feed intake is not related to physiological satiety mechanisms, because weaned pigs placed in a familiar environment consume 70% to 110% of the consumption levels observed in control pigs. The reduction in feed intake of pigs after weaning can be attributed to a reaction to an unfamiliar method of feed acquisition coupled with an unfamiliar source of feed (Bark et al, 1986). These factors can be minimized by management schemes that keep the pig eating through the weaning period. Experimentally, frequent liquid feeding is one method that can be used to accomplish this goal. A wasting-pig syndrome has been described in which, within 2 weeks after weaning, up to 7% of all weaners may exhibit a decrease in weight gain of more than 50% compared with piglets from the same origin, of the same age, and maintained in the same environment. Affected pigs have a prominent dorsal spine because of weight loss and impaired growth, and their hair appears longer than normal (Kyriakis and Andersson, 1989). Based on the suggestion that this syndrome may be associated with social stress after weaning in some pigs, amperozide, a psychotropic drug, has been used in an attempt to modify emotional behavior in response to the social stress, but it is too early to make any recommendations concerning its routine use.

Creep Feed and Postweaning Diarrhea

The relationships between the composition and amount of creep feed consumed by pigs before weaning, and the composition and consumption of the weaner diet after weaning as possible contributing factors to postweaning diarrhea and growth check, have been examined. Many factors interact at weaning time and culminate in these problems, including age at weaning, nutrient density of the diet, amount of feed intake, previous intake of creep feed, and factors that influence the proliferation of hemolytic *E. coli*. The inadequate ingestion of creep feed before weaning has been suggested to have a priming effect that causes a transient hypersensitivity to feed antigens in the immediate postweaning period, leading to an enteropathy and a predisposition to enteritis caused by *E. coli*. It had been suggested that total creep-feed intakes of at least 400 g/piglet before weaning were required for the development of mature intestines in order to minimize the incidence of postweaning diarrhea. The absorption of feed antigens by the intestine of pigs weaned at 3 weeks of age, with the subsequent development of an immunological response to dietary proteins in the intestines, has also been examined as a possible contributing factor in postweaning diarrhea (Wilson et al, 1989).

Recent evidence disputes the hypothesis that postweaning diarrhea occurs as a result of an intestinal hypersensitivity to weaner diets (Sarmiento et al, 1990). Weaning at 3 weeks of age causes large, rapid reductions in lactase activity at most sites along the small intestine; sucrase activity also decreases temporarily but then recovers. Minimum values of enzyme activities occur about 4 to 5 days after weaning. Similar changes occur whether or not creep feed is consumed before weaning. Continued consumption of creep feed by unweaned pigs up to 32 days of age led to small but significant reductions in lactase activity. The large loss of digestive enzyme activity in the brush borders of small intestines in weaned animals coincided with a reduced ability to absorb xylose and impairment of growth rate in otherwise healthy piglets. A loss of enzyme activity in this period could help to explain reduced growth rates, as well as the occurrence of a malabsorption syndrome. In weaned pigs, there is a marked increase in the depth of the small intestinal crypts and a marked reduction in the height of the villi, causing a reduction in the absorptive area of the small intestine. The pig has sufficient pancreatic and gastric enzyme activity so that performance should not be limited, except possibly during the period shortly after weaning. Attempts to reproduce an intestinal hypersensitivity response to weaner diets by feeding pigs small quantities of preweaning diets have been unsuccessful. When postweaning diarrhea occurred, it was associated with an earlier, more prolonged, and greater proliferation of enterotoxigenic *E. coli* in the small intestine than the diarrhea that occurred in healthy pigs after weaning. The greater proliferation in pigs that developed diarrhea could not be attributed to an excessive dietary intake after weaning or to a specific proliferation of rotaviruses. The underlying mechanism for the greater proliferation of hemolytic *E. coli* and the development of postweaning diarrhea in some pigs and not others in the same group are unclear.

The incidence of postweaning diarrhea in a herd is related to the age and weight at weaning and the size of litter (Svensmark et al, 1989a-d). In a survey of intensively managed Danish sow herds, the incidence of diarrhea increased with litter size at weaning. Litters weaned before 2 weeks of age had a twofold risk of developing diarrhea after weaning and a 2.4-fold higher mortality rate than did litters weaned at 6 to 7 weeks. Litters weaned at an individual piglet weight below 3 kg body weight had a threefold higher risk of developing diarrhea after weaning and a fivefold higher mortality rate than did pigs from litters weaned at 7- to 8-kg individual piglet weight (Svensmark et al, 1989d). Diarrhea after weaning was also associated with an increased incidence of diseases of the skin and respiratory tract.

The pathogenesis of *E. coli* postweaning diarrhea in weaned pigs is less well defined and appears to be more complicated than that of neonatal diarrhea. The apparent complexity of postweaning enterotoxigenic *E. coli* infections may be attributable to the effects of factors associated with weaning. These factors include the stress of weaning, cessation of lacteal immunity, selection for antibiotic-resistant enterotoxigenic *E. coli* by antibiotics in feed, and decreased gastric bactericidal activity caused by temporarily increased gastric pH. Other factors, such as reduction in ambient temperature and change in diet and preweaning exposure to diets fed at weaning, are associated epidemiologically with the development of *E. coli* diarrhea in weaned pigs. These factors have been described in the section on nutrition of the weaned pig. The inherited susceptibility of a herd to a particular strain of enterotoxigenic *E. coli* is also a determining factor.

The provision of high-energy, high-protein milk and milk by-products–based preweaner diets (e.g., creep feed), beginning when piglets are about 10 days of age, is used commonly to encourage piglets to eat dry feed early in life and through the weaning period. The concept is sound, and many creep feeds have been developed, all of which have as their primary purpose making the pig eat so that it becomes less dependent on sow's milk and weans onto a weaner diet with a minimum of nutritional stress. The major problem has been failure of the pig to eat a significant amount of the

dry diet before weaning. Therefore, after weaning, there is a period of 7 to 14 days before the pig adjusts to the diet. The use of phased feeding programs has been recommended. As animals reach specific weight ranges after weaning, dietary formulations are made to account for the evolving digestive capacity of the pigs and the availability and cost of the ingredients (Dee, 1999).

The presence of other stressors at weaning, such as the mixing of litters, crowding, uncomfortable weaner pens, and behavioral abnormalities such as fighting and tail biting, may exacerbate the effects of postweaning growth check because of inadequate feed intake.

A common practice among swine producers is to restrict feed intake during the early postweaning period to reduce the incidence of diarrhea in pigs. Some reports indicate a higher frequency of digestive disturbances in weaned pigs when fed ad libitum than when feed is restricted. However, restriction of feed intake significantly reduces performance. Diarrhea also reduces performance, but feed restriction reduces performance more than diarrhea. Restriction of feed intake by limiting weight of feed provided per day reduces the incidence and severity of postweaning diarrhea, but the overall performance of pigs until they reach 90-kg live weight may be unaffected by feed restriction or diarrhea. It is suggested that piglets weaned at 3 weeks of age be offered high-density diets ad libitum, but for pigs weaned at 4 weeks of age, there may be no advantage to higher-nutrient-density diets. Experimentally, strategic feed restriction during Days 3 to 8 after weaning, of pigs weaned at 5 weeks of age, reduced the occurrence of postweaning diarrhea and the proliferation of haemolytic *E. coli* without these problems when ad lib feeding was resumed (Rantzer et al, 1996). During the restrictive period the restricted-fed pigs had a lower diarrhea score, fewer number of antibiotic treatments, and a lower percentage of fecal haemolytic *E. coli* than the full-fed pigs. The performance of the full-fed pigs was suboptimum during the restrictive period as compared with the period after, which may be due to a peak in postweaning diarrhea and an increase in haemolytic *E. coli*. This suggests that a strategic feed restriction during the period of 3 to 8 days after weaning can reduce the proliferation of haemolytic *E. coli* and the occurrence of postweaning diarrhea for 14 days after weaning.

Water for Weaned Pigs

Weaned pigs must be provided with adequate supplies of water. A 6-kg weaned pig consumes about 103 g/kg live weight/day, and a 12-kg pig consumes about 246 g/kg live weight/day. Daily feed intake is the best predictor of water intake, and the relationship can be described by the following equation:

$$\text{Water intake (L/day)} = 0.149 + 3.053 \text{ Feed intake (kg/day)}$$

The reported ratios of water to feed intake have varied from 2:1 to 5:1. The pattern of water intake over the first 5 days after weaning also varies. In some cases, pigs will not consume water until Day 2, which may be explained by the piglets not finding the source of water when first introduced to the weaner pens. The presence of water from a leaking drinker may encourage drinking, and once drinking has commenced, consumption increases rapidly. Water deprivation of weaned pigs, as the result of a faulty watering system, can lead to salt poisoning (Marks and Carr, 1989). The pig is adaptable to restrictions of its water supply, but there are limits of adaptation. As pigs get heavier and ambient temperatures rise, attention to water flow rate becomes more important.

Maintenance of Systemic and Intestinal Immunity

During the first month of life, the piglet is dependent on the sow's colostrum and milk for both systemic and intestinal immunity. The intestine of the newborn piglet absorbs intact immunoglobulin molecules from ingested colostrum for 24 to 48 hours after birth, which provides a broad-spectrum of protection, primarily against systemic infection, for the first few weeks of life. Whereas colostrum provides the piglet with circulating immunoglobulins, the sow's milk provides secretory antibody (i.e., IgA), which becomes the predominant immunoglobulin in milk and provides passive intestinal immunity from a few days after birth until weaning. At about the time of weaning, piglets develop their own intestinal antibody, which can be extrastimulated by the use of oral vaccines administered in the feed (Bourne and Newby, 1981). The endogenous production of intestinal IgA begins to develop rapidly in the pig at about 3 weeks of age.

Therapeutic and Subtherapeutic Use of Antimicrobials

The advantages and disadvantages of using antimicrobials in animal and plant agriculture continue to be debated in the literature. The use of antibiotics as growth promotants in food animal production is highly controversial. The advantages for the producer are economic benefit resulting from greater uniformity of growth and reduction in morbidity. Typically, the improved performance is 4% to 8% in gain and feed efficiency. For the consumer the advantages are that the pork is produced at a reduced price, potentially contaminated with fewer bacteria, and arguably produced with increased welfare for the pig. The disadvantages for the producer are the consumer and political pressures to not use growth promoters, the possible suppression of normal flora, and the possible failure of antimicrobial therapy because of resistance induced by subtherapeutic use. The disadvantages for the consumer are the possible tissue residues in pork and the possibility of infection with antimicrobial-resistant bacteria that emerged in pigs fed subtherapeutic antimicrobials.

Growth-promoting concentrations of antimicrobial agents modify the microflora and their products within the gastrointestinal lumen and probably within the host's immediate environment. Growth promotion has been greatest with animals maintained under adverse managerial and environmental conditions. The antimicrobials and other growth promotants that are approved for use in swine feeds vary among countries. Each country publishes a brochure describing those products that are approved for use as growth promotants, their withdrawal periods, and their incompatibilities.

Antimicrobial Use and Resistance in Swine Herds

Some information is available on the use of antimicrobials in swine herds. They are used extensively in newly weaned pigs, a critical time for infections in young animals, and to a lesser extent in growing and finishing pigs, where their use may not be effective (Prescott, 1997). Raising pigs under intensified conditions has similarities to beef feedlots in which large numbers of animals are fed under intensified conditions.

A mail survey of swine herds in Ontario, Canada, in 1991, found that 86% of herds added antimicrobials to starter (weanling pig) rations, and only 29% added these drugs to finishing pig rations (Dunlop et al, 1998b). The most commonly used antimicrobials were tylosin, carbadox, and furazolidone in weanling pigs and tylosin, lincomycin, and tetracycline in finishing pig rations. Water medication of

growing-finishing pigs was practiced on 25% of farms; 80% of farms had injected at least some growing-finishing pigs with antimicrobials in the 12 months preceding the survey. Approximately 20% of herds that added antimicrobials to finishing rations did so for growth promotion purposes only, whereas others used them for the treatment of disease, prevention, control, or a combination of both. Among those not using antimicrobials in finishing rations, 83% did not consider they were necessary and 37% were concerned about the potential for residues in marketed pigs.

Antimicrobial use during swine production is associated with increased resistance to those antimicrobials among fecal *E. coli* of finishing pigs (Dunlop et al, 1998a). Antimicrobial treatment of groups of pigs has been shown to be more important than individual medication in increasing the risk of resistance among *E. coli*, but there was little evidence that group treatment practices increased the risk of resistance to gentamicin, which was used only for individual animal therapy. Antimicrobial use in starter rations was associated with resistance to ampicillin, carbadox, nitrofurantoin, sulfisoxazole, and tetracycline. Antimicrobial use in growing-finishing rations was significantly associated with resistance to ampicillin, spectinomycin, sulfisoxazole, and tetracycline. The results suggest that antimicrobial medication of rations of postweaning pigs selects for and maintains antimicrobial resistance among *E. coli* of finishing pigs. Similar studies indicate that patterns of antibiotic resistance are dependent on age of pig and level of antibiotic use (Mathew et al, 1998).

The prevalence of antimicrobial resistance among fecal *E. coli* of swine on farrow-finish-farms in Ontario were ampicillin (29%), carbadox (3.5%), gentamicin (0.6%), nitrofurantoin (27%), spectinomycin (28%), sulfisoxazole (38%), and tetracycline (71%) (Dunlop, 1998d). Between 30% and 76% of the variation in prevalence of resistance was explained by between-farm differences, indicating that farm-level factors may be important in explaining some of the variation.

Antimicrobial resistance was common on farms that did not medicate rations of postweaning pigs; the results indicate that antimicrobial use does increase the risk of resistance to the antimicrobials studied. The reduction of group medication with broad-spectrum antimicrobials of weanling and growing-finishing pigs might reduce the prevalence of resistant *E. coli* in market pigs. Thus antimicrobials should be used only when necessary, and the swine industry should continue to invest in the maintenance of a healthy population of pigs in which the need to treat with antimicrobials is reduced.

A survey of 34 farrow-finish swine herds in Ontario for individual and group antimicrobial drug use found that the rates of individual-pig treatment varied from 0 to 24.1 pigs treated/1000 pig-days, with a median of 5.29 (Dunlop et al, 1998c). Most individual treatments were given to piglets and sows at parturition, and penicillin was the most commonly used antimicrobial. Gentamicin was given to nursing piglets on some farms. Most herds either did not use any antimicrobials or used narrow-spectrum or broad-spectrum antimicrobials in the rations of postweaning pigs.

Information on the use of feed additives in swine herds was collected from 710 farms (Dewey et al, 1997a). Of all the feeds, about 79% contained feed additives used in the labeled manner. For all classes of pigs, the prevalence of labeled feed additive use was greater than 75%. Penicillin was used according to its label most often, followed by apramycin, bacitracin, tetracyclines, lincomycin, and tylosin. Carbadox had the highest prevalence of "off label" use. Of the 699 feeds that included feed additives in an off-label manner, about 57% included additives at greater than the recommended concentrations or were fed to an incorrect class of pig. About 56% of the feeds had "off-label" combinations of additives. Small farms were more likely to use rations with no feed additives than intermediate or large farms. Of those farms using feed additives, the odds of a small farm using all feed additives in the labeled manner was 7.7 times that of an intermediate or large farm. After controlling for herd size, producers who used a veterinary consultant were 2.1 times more likely to use feeds with feed additives.

Antimicrobial-resistant *E. coli* have been isolated from the fecal samples of veterinarians in different practice specialties (cattle, swine, poultry, or small animals) or in governmental veterinary medicine in the Netherlands (Bongers et al, 1995). The prevalence of *E. coli* isolates resistant to several antimicrobials was highest in cattle and poultry practitioners and lowest in swine practitioners. A significantly higher percentage of the isolates from cattle practitioners had a high level of resistance to ampicillin than did swine practitioners. A significantly higher percentage of the isolates from poultry practitioners had a high level of resistance to oxytetracycline than did the isolates from swine practitioners. The prevalence of antimicrobial resistance of *E. coli* isolates from veterinarians was relatively low compared with that of isolates from pig farmers, abattoir workers, and suburban residents. There was no resistance to carbadox in the fecal flora of participating veterinarians, but resistance was found in isolates from swine; this suggests that transfer by direct contact is unlikely.

The general aspects of using antimicrobials in the feed of pigs for the prevention of certain infectious diseases and for growth promotion, and the potential for the development of antimicrobial-resistant bacteria that may be transmissible to humans through the food chain, are described early in the chapter.

Housing and Environment (the Nursery)

The environment and housing factors that influence the performance of the early-weaned pig include temperature, humidity, air velocity, light, animal space, and hygiene. There has been much controversy about the optimum amount of floor space that should be allowed per pig, the best and most economical floor material, the ventilation system that will provide the best quality air, the optimum ambient temperature, the amount of feeder space per pig, and the feeding management. Weaning houses (e.g., nurseries) have now been designed and adapted to provide sufficient space and volume and a suitable environment for the weaned pig. In addition, reduction of labor requirements for piglet care has led to the design of weaner pens with wire mesh floors. However, wire mesh–floored cages favor an increase in radiative and convective heat losses, and, consequently, the critical temperature of the piglet is probably increased.

Air Temperature and Ventilation

The environment of the nursery is important and must include consideration of air exchange, humidity, dust levels, and temperature. The environmental temperature required at weaning varies with age. A range of 29° to 30° C has been recommended as a guideline when weaning age is 3 weeks or younger (Dee, 1999). This temperature should be maintained for the first week after weaning and gradually decreased as the pigs increase in size. The temperature should decrease at least 10° C during the 7- to 8-week nursery period, resulting in levels of 20° C to 21° C when the pigs weigh 20- to 25-kg body weight. Optimum air temperature for piglets weaned at 5 weeks is about 25° C. At lower

temperatures, growth rate and feed efficiency are reduced. Cold weather also increases pig mortality by affecting the immune system of the pig.

Because of the considerable magnitude of convective heat losses in piglets reared in batteries, air velocity is an important factor to consider in addition to air temperature. Weaned piglets are more comfortable, grow faster, and consume less feed in a draft-free environment. Proper ventilation rates are critical to providing fresh air for breathing and controlling humidity and residual gases. At levels of 50 ppm, atmospheric ammonia may affect lung clearance mechanisms. During the winter months, improperly adjusted propane heaters may lead to elevated carbon monoxide levels. There are no documented data on the optimum relative humidity for early-weaned piglets

The presence of bedding, such as straw or wood shavings, may help the piglets to create a microclimate that protects them from the adverse effects of climate and that considerably reduces heat losses. The provision of straw on a solid floor improves the welfare of weaned piglets. When straw is provided, piglets chew and root in it, which provides a form of recreation and may reduce chewing of penmates. Up to 25% of active behavior is straw-directed behavior. Any reduction in chewing of penmates may be beneficial, because serious tail and ear biting can cause great economic loss. The preference of weaned pigs for a bedded or concrete floor depends on temperature. Under warm conditions, straw is likely to benefit pigs because of its recreational value but not as a means of improving comfort in the resting area.

Rearing in complete darkness is considered favorable, since it reduces aggressiveness in animals of different litters that are mixed after early weaning.

All-In, All-Out Pig Flow

The AIAO management system is recommended for early weaned pigs. The weaner pens are depopulated, cleaned, disinfected, left vacant to dry for a few days, and then restocked with newly weaned pigs. Average daily gain and feed conversion are better in pigs reared in an AIAO system compared with those reared in the continuous system. The improvement is probably the result of the reduction of microbiological flora in the environment through cleaning and disinfection. Continuous occupation of weaner pens by successive litters of weaned pigs without cleaning and disinfection between litters causes a marked increase in the population of infectious diseases.

Stocking Density and Floor Space

As swine producers continue to intensify to increase productivity, the need to increase the density of nurseries to reduce building and operating costs per pig is important. An increase in the density of groups of weaned pigs to a crowded level decreases average daily gain, increases the ratio of feed/body weight gain, and promotes aggressiveness.

As floor space decreases from 0.25 to 0.17 to 0.13 m^2/pig, average daily gain decreases and continues to do so with each successive growth period. A depression in growth rate caused by overcrowding during the weaner phase affects subsequent growth rate throughout the growing period (Van Lunen, 1983). In weaner pigs reared at densities of 0.37, 0.18, and 0.12 m^2/pig on decks or floors, there were marked differences in rate of gain, days to market, and backfat thickness in favor of the lower density of 0.37 m^2/pig.

Decking has been an effective way of increasing nursery density. Properly designed double- and triple-deck environmentally controlled nurseries can provide the means of meeting the environmental needs of the pig during the critical postweaning period. The building and operating costs per pig can be reduced without adversely affecting pig performance. There are no significant behavioral problems, and the pigs usually remain clean because the feces pass through the expanded metal floors. Field trials suggest that 10 weaned pigs from 5- to 12-kg body weight may be housed per 1.2- × 1.2-m cage and that a maximum of eight pigs from 12 to 22 kg may be housed in the same size cage. Factors influencing the space requirement include the starting weight, length of time that pigs will be kept in the nursery, environmental conditions and the degree of environmental control, type of floor, amount of feeder space per pig, type of feeder, and number of pigs per pen. Space recommendations for optimum performance of weaned pigs with an initial weight of 5 to 11 kg range from a low of 0.09 m^2/pig to a high of approximately 0.28 m^2/pig. Piglets raised on perforated-sheet floors may experience a greater incidence of traumatic injuries on legs and feet than piglets kept on concrete floors, and piglets kept on mesh floors might have a greater incidence of injury than those kept on perforated floors.

Feeder-Space Allowance

Feeder-space allowance can affect weaner-pig performance. Pigs have a minimum feeder-space requirement below which daily feed intake is decreased, with a concomitant decrease in daily gain. However, an increase in feeder space above the minimum does not improve the daily feed intake and subsequent daily gain. Some studies show that three 15.2-cm sections of feeder space are adequate for 122- × 122-cm or 91- × 122-cm nursery pens when those pens contain 12 or fewer pigs (Lindemann et al, 1987). It may be advantageous to shorten trough length when possible to prevent fouling and wasting of feed resulting from urination and defecation in feeders that extend the total length of one side of the pen. When feed is supplied ad libitum, pigs are not required to eat as a group and therefore do not require enough trough space to accommodate all pigs at the same time.

TECHNOLOGIES USED TO IMPROVE THE HEALTH AND PERFORMANCE OF THE WEANED PIG

No other factor can affect the productivity and profitability of a swine farm as severely as exposure to an infectious disease(s). Bacterial and viral agents that affect weaned pigs are frequently spread laterally among populations of pigs with varying levels of immunity. Concurrent infection of multiple pathogens also can occur. One of the essential roles of the swine practitioner is to implement strategies to reduce the effect of such pathogens. The following review summarizes the published data health technologies commonly used to improve the performance of weaned pigs: AIAO pig flow, the F-10 system, multisite systems, whole herd depopulation-repopulation, and PD.

All-In, All-Out Pig Flow

AIAO pig flow has been documented to improve the performance of pigs (Clark et al, 1991; Scheidt et al, 1995). The ability to completely empty a room, building, or site prevents the continuous spread of pathogens from older to younger animals. AIAO has long been a practice in the poultry industry. Poultry barns are routinely emptied following delivery of the birds to the slaughterhouse, washed, disinfected, fumigated, and allowed to remain empty for a period of time to reduce microbial survival outside the host. This technology was initially adopted by the swine industry for the control of diarrhea before weaning. The effects of AIAO

on the postweaning pig performance have been studied extensively. Studies demonstrate that such practices improve average daily gain and feed efficiency and prevent mortality and the severity of respiratory disease in both the nursery and growing-finishing phase (Clark et al, 1991). AIAO can be practiced by room, building, or site. Data indicate that AIAO by site or airspace leads to better performance than if a single room is emptied (McManus, 1991). Although piglets ideally should be within a week of age of each other, 2 weeks' production can be housed together and still see benefits. Studies also indicate that despite an improvement in overall pig performance, AIAO does not appear to eliminate the disease (Clark et al, 1991). Implementation of AIAO does, however, cause a reduction in the prevalence of pneumonic lesions, as well as a reduced severity of intestinal diseases (e.g., ileitis). Conversion of large, continuous flow facilities to AIAO usually requires construction of walls to establish rooms of pigs within buildings. Each room must be individually ventilated. Another means of converting to AIAO pig flow may require the reorganization of farrowing schedules, causing larger "batches" of weaned pigs, completely filling a facility at one time. Although it does take prior planning, the effect of AIAO on postweaning performance appears to be well worthwhile.

F-10 System

F-10 stands for "farrowing to 10 weeks of age" and is a technology that has been successful for the improvement of weaned pig performance (Schuiteman, 1993). In this system, sows are weaned in the normal fashion, but the pigs remain in the farrowing crate until they are 10 weeks old. The farrowing crate is then modified and converted to a nursery pen. The advantage of such a system is that early removal of the sow prevents further spread of infectious agents from sows to weaners, a reduction of labor, and improved performance. Although little data are available, it appears that piglets raised under the F-10 system perform much better than those raised under conventional measures. Improvements in growth rate of 44% and a 50% reduction in mortality have been recorded (Schuiteman, 1993). The disadvantages of such a system may include a reduction in the utilization of farrowing crate space. Therefore the system may be applicable only to producers using batch or group farrowing schedules. Despite this limitation, pigs raised under the F-10 system appear to be capable of better performance than those in conventional nurseries.

Multisite Systems

Before the description of SEW, a brief review of the current production systems in the United States is presented here (Dial et al, 1992). The U.S. swine industry currently uses either one-, two-, or three-site production systems. One-site consists of breeding, gestation, and farrowing on one site, with the nursery and finishing on separate sites. Recommended distances between sites range from 1 to 3 km depending on the health status of the operation and the suspected airborne potential of various microorganisms. Two-site systems consist of breeding, gestation, and farrowing on one site, with nursery-finishing on another. The main premise of both systems is that the nursery must be located on a separate site away from the breeding herd (Dee et al, 1993). This is important to prevent the transmission of pathogens from the sow to her offspring. This theory has been the basis of SEW technology and is summarized in a later section.

Multisite production systems have many advantages for swine producers, besides the improvement of health status. If nursery and finishing facilities are relocated on other sites, existing facilities can be remodeled to expand the size of the breeding herd, usually with reduced investment. Nurseries can be remodeled into farrowing rooms, and finishing pens can house gestating sows. Frequently, swine producers network together and establish off-site weaning facilities to commingle pigs from several farms. The health status between the sow farms must be similar in order to prevent the exposure of susceptible pigs to new diseases. Three-site production can be costly and difficult for the majority of smaller commercial U.S. swine producers to use. It is usually reserved for breeding stock companies or large herds with 1200 or more sows. The two-site system is much easier to operate economically and appears to be just as effective. This technology in combination with the SEW program is beneficial to all types of procedures and leads to improved efficiency of the swine enterprise.

Segregated Early Weaning

SEW, performed to improve the efficiency of swine production, is a common practice in the commercial swine industry. The procedure is used to control infectious disease with the primary objective of improving productivity of the growing-finishing phase of production (Dritz et al, 1994). The procedure attempts to prevent and minimize the transfer of infectious diseases by segregating pigs at weaning. The pigs can be segregated by removing the sows to a centralized breeding and gestation facility and leaving the piglets on the site or by transporting the piglets from the farrowing site to another site. The movement of weaned pigs or sows prevents the vertical transmission of infectious diseases. The weaned pigs are placed in groups, and each group remains segregated by the use of AIAO production. The group segregation prevents the horizontal transmission of pathogens between groups.

SEW prevents vertical transmission of pathogens that do not cross the placenta. Vertical transmission of pseudorabies virus, TGE virus, *A. pleuropneumoniae, M. hyopneumoniae, Serpulina hyodysenteriae, B. bronchiseptica,* and toxigenic *Pasteurella* have been prevented by SEW. Respiratory infections caused by *A. pleuropneumoniae, M. hyopneumoniae, B. bronchiseptica,* and toxigenic *Pasteurella* have not been eliminated consistently by the use of traditional, on-site, disease-elimination programs. Vaccination and the strategic use of antimicrobials have been used traditionally for the control of these respiratory diseases but are unreliable.

SEW is a variation of *medicated early weaning* (Alexander et al, 1980). Further reports have indicated the ability to eliminate certain pathogens and improve weaned pig performance. A critical component of the program consists of hyperimmunization of the sow before farrowing to provide high levels of colostral antibodies against specific pathogens. This is important to reduce transmission of pathogens between sows and pigs during lactation. The pig is then injected with a series of antibiotics to eliminate specific bacteria before weaning. Finally, the pig is weaned at an early age to a separate site to prevent further transmission from the sow. Regarding the necessity of antibiotics, under controlled conditions, age-specific separation from the sow may be more important than medication (Clark et al, 1994). The relationship between weaning age and pathogen elimination has been examined (Clark et al, 1994). It currently appears impossible to eliminate certain pathogens with early weaning. *E. coli,* and *Str. suis* may be present in the pig shortly after birth (Day 1) because of colonization through contact with the mucosal surfaces, secretions, or excretions of the sow (Amass et al, 1996).

Transplacental transmission of PRRSV, *Leptospira* sp., or parvovirus may lead to the presence of these specific

pathogens immediately after parturition. The pathogens can be eliminated if certain weaning ages are met. Weaning age is critical to the success of SEW because the maternal immunity provided by colostrum decreases at different rates for different diseases (Dritz et al, 1994). Weaning pigs at 10 days of age or less appears to eliminate *H. parasuis, B. bronchiseptica, P. multocida,* and *M. hyopneumoniae*. The initial presence of these pathogens is not detected unless weaning ages reach 15 days or more. Similarly, *A. pleuropneumoniae* may be eliminated at 16 to 18 days of age. Finally, pseudorabies virus and TGE virus appear to be eliminated at 21 days of weaning.

On arrival at the nursery, weanlings are fed diets high in milk products and plasma proteins. It is critical to limit feed 5 to 7 times daily for the first week after weaning. Pigs are placed on a water-soluble antibiotic, selected on the basis of in vitro sensitivity testing. Four different diets are usually fed over the 8-week nursery period. Animals are housed in single stage nurseries with plastic coated flooring at 30° to 31° C and are sorted by size and sex.

The selection of vaccines and medications to use depends on the individual farm diagnostic data. It is recommended that nasal swabs be collected from sows and that two to three sick pigs from the nursery and finishing areas be submitted to the diagnostic laboratory for culture. Medication can be chosen based on the sensitivity patterns of bacterial isolates. Serology is also an important diagnostic aid to determine the exposure level of the breeding herd to specific pathogens that are targeted for eradication and assists with the development of vaccination programs for the breeding herd.

A. suis, H. parasuis, and *Str. suis* have emerged as important pathogens of swine, particularly in high health status herds (MacInnes and Desrosiers, 1999). They are considered opportunistic pathogens, and environmental and host risk factors need to be considered in the clinical management of these diseases. They have become known as the "suis-ide" diseases. They are early colonizers and, for that reason, are difficult to control by management procedures such as SEW. The efficacy of the vaccines and serodiagnostic testing are complicated by the presence of multiple serotypes, cross-reactive antigens, and absence of clear markers for virulence. Control is dependent on the use of antimicrobials for treatment of individual animals and strategic medication of the feed and water supplies, improvement of housing and management, and consideration of vaccines.

Some studies found no significant differences in average daily gain, feed:gain ratio, or average daily feed intake among pigs moved to offsite nurseries or in pigs maintained in a strictly sanitized environment compared with pigs reared in an onsite sanitized environment or in an environment where the sows are moved away from the pigs with the pigs remaining in the same crates in which they were farrowed (Fangman et al, 1996b). Production systems practicing good sanitation and conscientious biosecurity measures to establish a minimum pathogen exposure may not demonstrate significant performance results in nursery pigs moved offsite at an early age (<14 days). Weight at weaning may be a more important factor than age at weaning (if <21 days) in terms of subsequent growth performance (Fangman et al, 1996a). Site separation may not eliminate transmission of selected infectious agents. In some studies, pigs at all off-sites were culture positive for *Str. suis* and toxigenic *P. multocida*.

Comparison of the growth performance of segregated early-weaned pigs with conventionally weaned pigs through finishing found that SEW pigs weigh more at the end of the nursery phase, but they did not maintain that advantage through finishing (Drum et al, 1998). Also, vaccination may temporarily slow the growth of SEW nursery pigs, but the effect does not persist through finishing. A partial budget analysis can be used to predict how a change from conventional weaning to SEW, with a concomitant increase in the size of the breeding herd, affects profitability in a hypothetical herd (Drum and Marsh, 1999).

The use of antibiotics is not the most important factor for disease control in SEW programs (Dritz et al, 1996). Vertical transmission of *M. hyopneumoniae* was prevented by weaning pigs at 7 to 10 days of age and segregating them off-site, without the use of medication. Minimizing the use of antibiotics in disease-control protocols reduces the costs and the need for extra-label use of drugs. A low-cost, modified, medicated-early weaning program to eliminate *M. hyopneumoniae* has been examined (Dee, 1994). Pigs received a series of injections of oxytetracycline on Days 1, 7, and 14 of age. Pigs were weaned at 14 days of age to off-site nurseries. The organism was not detectable in tissues at slaughter and serologically. Performance was improved and is recommended as an effective low-cost program for improving the health and performance of growing pigs in a commercial herd.

Success of a SEW program depends on the commitment of the personnel managing and operating the system. A multiple-site operation requires discipline, coordination, and excellent management as the foundations of success. Strict AIAO pig flow is a necessary component of SEW.

Biosecurity and disease surveillance are important components of SEW. The suggested biosecurity measures for SEW include the following:

- Locate as far away from other pigs as possible; early-weaned pigs have are highly susceptible to infection
- Evaluate disease status of herd or origin
- Isolate all incoming breeding stock to prevent introduction of pathogens
- Maintain continuous disease surveillance by a veterinarian; this includes necropsies, serological testing, and abattoir surveillance
- Continuously evaluate of production records; feed intake and growth rate are sensitive nonspecific indicators of disease
- Educate animal attendants to recognize the early clinical signs of disease.
- Prohibit vehicles that have not been cleaned and disinfected from transporting pigs
- Use proper load out facilities that ensure a pig leaving the complex cannot return
- Use aggressive control procedures for rodents, flies, and stray animals
- Exclude all nonessential personnel from the farm
- Ensure that farm personnel have no contact with swine outside the herd
- Use pathogen-free feed sources
- Institute methods of feed delivery that closely control access of potentially contaminated trucks into the farm
- Dispose of dead animals promptly
- Use fences and locks to restrict entry of unauthorized personnel

Whole Herd Depopulation-Repopulation

Whole herd depopulation-repopulation has gained increased acceptance as a strategy to improve both health and genetic performance. Although the process can be very costly and extremely difficult psychologically, it is very effective at eliminating chronic, endemic diseases and at improving genetics at the same time. Reasons to repopulate the entire farm include poor growth rate, excessive numbers of nonmarketable or cull pigs, poor feed efficiency, and low heterosis (Dial et al, 1992). Diseases of the nursery pig are typically not severe enough to warrant whole herd depopulation.

A brief outline of the strategy is presented here. Before initiation of a depopulation program, prior planning is required. A careful evaluation of the current herd performance is necessary, including the identification of all significant disease entities currently in existence. Commonly encountered disease problems that lead to depopulation including pseudorabies, swine dysentery, *A. pleuropneumoniae*, and AR. Such chronic disease usually leads to excessive antibiotic use (Deen, 1992). It is important to establish the amount of antibiotics or vaccines that are being used to manage disease, in order to assess the potential economic benefits of a whole herd repopulation.

In addition to the assessment of current health problems, an evaluation should be made of the genetic status of the herd. Problems that indicate poor genetic performance include low live born litter size, low weaning weights, and excessive backfat at slaughter. Finally, because whole herd depopulation causes severe short-term capital losses, arrangements frequently must be made with a lending institution to provide an adequate level of working capital (Deen, 1992).

The timing of the depopulation is critical. Procedures should take into account the length of downtime required, season of the year, and predicted market prices. Ideally, to decrease downtime, facilities are rented to ensure a constant flow of pigs to market (Leman, 1992). At least 30 days of downtime are usually required on the home farm to allow for thorough cleaning and repairs and to reduce the survival of pathogens outside the host. Ideally, this should take place during periods of hot weather to take advantage of the bactericidal or virucidal effects of drying, heat, and ultraviolet radiation. The clean-up procedure is very involved and encompasses the washing of the entire swine complex, including a thorough cleaning of the pit. All equipment, including feeders, crates, pens, and ventilation equipment, needs to be washed thoroughly with hot (90° to 94° C), high-pressure water and disinfected (Leman, 1992). Pits should be emptied and slats lifted to obtain access to fecal material that has built up on the underside of the concrete (Leman, 1992). In addition, a rodent control program should be implemented and maintained, ideally, by a professional exterminator.

Improved performance is usually seen after repopulation (Leman, 1992). Improvements of 10% or more in growth rate, and a 5% to 10% improvement in feed efficiency, have been reported. Other benefits include a 10% to 20% increase in pounds marketed and a reduction in vaccination and medication costs. Problems frequently encountered during or after a repopulation consist of mismanagement of the offsite breeding project, reintroduction of a significant disease through the purchased stock, and the enhanced level of specific diseases such as greasy pig disease or parvovirus. Such diseases are thought to arise from a low level of immunity within the immature breeding population. Overall, whole herd depopulation and repopulation can produce both health and genetic benefits. However, because of its high level of economical and psychological stress, it is a technology that should be used only when other options have been exhausted.

Partial Depopulation

PD, in contrast to whole herd depopulation, involves the emptying of a single stage of production rather than removal of all pigs at one time. ND has been studied extensively and is a cost-effective means of interrupting horizontal transmission of PRRSV from older, infected pigs to those recently weaned (Dee and Joo 1994a). Significant improvements in nursery pig daily gain, mortality, treatment cost, and profitability have been recorded after implementation of nursery depopulation (Dee et al, 1997a,b). Despite such improvement, reinfection of nurseries with PRRSV is a frequent event, often taking place 12 to 18 months after completion of the depopulation protocol. Thus it is possible that the primary benefit of this strategy may be for the control of opportunistic pathogens, rather than control of the PRRSV. Nursery depopulation consists of emptying, washing, and disinfecting all nursery rooms and allowing the facility to remain empty for a minimum of 2 days. Because of the poor viability of PRRSV outside of the pig, extended periods of downtime can be avoided, enhancing facility use and eliminating the virus from the nursery pig population. Disinfectants frequently recommended include phenol- or formaldehyde-based products to reduce survivability of the virus in the environment (Pirtle and Beran, 1996). This strategy can also be applied to finishing populations.

HEALTH MANAGEMENT AND PRODUCTION OF THE GROWING AND FINISHING PIG

In farrow-to-finish herds, after rearing in the nursery, the pigs are transferred to the growing and finishing pens at about 25 kg of body weight, where they are fed until they reach market weight at about 100 kg of body weight and are (1) sold for pork, selected as breeding stock, and kept as herd replacements, or (2) sold as breeding stock to other farms.

Some feeder-pig enterprises purchase 20- to 25-kg pigs from a variety of sources and feed them until they reach market weight. These growing-finishing units may feed several hundreds or thousands of pigs annually and are commonly integrated with a feed company that supplies financing, feed, and professional veterinary consultation. The emphasis in these units is on producing body weight gains with the lowest possible cost per unit of gain.

The major objective during the feeding phase of pig production just described is to grow and finish the pig as rapidly as possible and to still obtain a lean pig that will yield the highest carcass score possible to obtain maximum economic returns. Because feed represents approximately 70% of the cost of production, obtaining maximum feed efficiency during the growing-finishing period is a major determinant of net profit, and the producer and veterinarian must think in terms of using whatever means are available to lower feed costs. The costs of production and profitability vary among herds. Using some Canadian data, 96% of the variation between herds is explained by days to market, mortality rate, total feed consumption, carcass weight, and incoming feeder-pig weight.

Causes of Economic Losses in Growing-Finishing Pig Production

Death losses of growing-finishing pigs are a major cause of economic loss. Published percentage mortality of growing-finishing pigs varies from 0.2% to 7.5% (Losinger et al, 1998b). It has been suggested that less than 2% mortality is excellent, and more than 4% is poor performance. Over a 6-month period, the mean mortality risk based on a 1995 NAHMS study of swine operations with 300 or more market pigs, was 2.3% ± 0.2% in the growing-finishing production phase (Losinger et al, 1998b). Mortality was 4% or higher in 13.5% ± 2.9% of growing-finishing operations, whereas mortality was 2% or less in 63.6% ± 5.3% of operations. Factors associated with a mortality of 4% or higher included a mean weaning age 28 days or less and not obtaining all growing-finishing pigs from farrowing units belonging to the operation. The decision to not provide growing-finishing pigs antibiotics or other agents in the feed or water for disease prevention or as growth promotants, and the ranking of producer organizations as very or extremely important

sources of antibiotic information, were associated with 2% or less mortality in the growing-finishing phase (Losinger et al, 1998b).

Respiratory disease is the leading cause of pigs during the growing-finishing phase of production (Losinger et al, 1998c). In herds with 300 or more market pigs, 61.7% of operations reported at least one death from respiratory disease. Mean mortality resulting from respiratory disease was 0.9% ± 0.1% of finishing pigs/operation. Risk factors associated with operations reporting 2% or higher mortality included having 3000 or more pigs enter the growing-finishing unit over a 6-month period; diagnosis of *Haemophilus* spp. or *A. pleuropneumoniae* infection in pigs in the previous 12 months; and keeping of pigs in the growing-finishing unit longer than 120 days (as compared to less than 100 days). With no farrowing facility, mean weaning age less than 28 days, and below 50% of finishing pigs on only solid concrete were associated with reports of 2% or higher mortality attributed to respiratory disease.

The estimates of feed-conversion ratio of finishing pigs in the United States range from 2.18 to 5.91 kg of feed fed for each kilogram of live-body weight gained during the growing-finishing phase, with a mean of 3.28 ± 0.52 (Losinger, 1998). The management factors associated with improved feed-conversion ratios include: three or more different rations fed during the growing-finishing phase; no rations mixed on the farm; and not giving chlortetracycline in feed or water as a disease preventive or growth promotant. The ratio was better in operations in which 3000 or more pigs entered the growing-finishing production phase during the 6-month period before the interview compared with those in which fewer than 3000 pigs entered.

Monitoring Growing Pig Production

Production Records

The details to be collected for growing-finishing pig records to be analyzed retrospectively are simple. Pigs are recorded as being located within a group or at a certain location over a time period. Feed is added to this group or location, and dead and culled pigs are removed. Finally, the pigs are marketed and the pigs are counted and weighed at entry and exit. Even more benefit may be gained when those weights are measured individually. From this information is gained estimates of average daily gain, feed conversion, mortality rates and cull rates. In addition to this information, carcass weights and characteristics can also be provided to provide estimates of the qualities of the end product.

Growing-finishing data are simple but involve varying amounts of labor. It is not the ability to collect grow-finish records but the utility in their collection that inhibits many farms from collecting the data. On many farms, the data collected are underutilized. In many cases a group of pigs is monitored and the describing characteristics are only calculated after all of the pigs leave the farm. These describing characteristics are usually limited to a few numbers such as average daily gain, feed conversion, mortality rate, and cull rate. If there is a problem, the numbers are not easily broken down to try to describe reasons by which they are inadequate. Greater detail is needed to provide adequate definition of problems and solutions in many cases. It is my experience that the most common measurement of pig performance in pursuing the aid of a veterinarian is usually sick or dead pigs, especially pigs that die suddenly. This reliance on mortality may lead to an overemphasis of factors that do not have an overall effect on profitability that is as great as some other factors:

- *Mortality and morbidity rates:* In addition to the pathological and clinical examination of affected pigs, an examination of the patterns of mortality is often useful. If the mortality can be graphed against the age of pig or the calendar date, patterns of mortality can be defined and precipitating circumstances are often seen. In many cases, mortality groups around seasonal changes in temperature or certain ages that may coincide with feed changes or increases in competition within the pen (Abiven et al, 1998).
- *Average daily gain:* It is best to graph average daily gain against the age of the pig and to compare average daily gain with and without the inclusion of mortality and culls. In many cases average daily gain does flatten out at approximately 70-kg live weight. This may reflect a number of combined occurrences, including respiratory disease and crowding as well as feed changes. The average daily gain is often best compared between barrows and gilts to ascertain that both genders are being affected equally (Dewey, 1993).
- *Feed efficiency:* Even though feed is the major cost in growing-finishing units, precise data on utilization of feed is often not available. Feed efficiency changes over the age of the pig with drastic changes occurring in certain genotypes. This is especially important to evaluate as increasing carcass size is considered. The use of collection pans under the slats is laborious but often exhibits a poor feeder-adjustment regime. Seasonal variations in feed efficiency are also important to monitor; the use of pig feed to keep them warm is expensive under most rearing regimes.
- *Average daily feed intake:* Although this index is relatively easy to monitor in all-in, all-out barns, it is just beginning to be used as an indirect measure for pig growth and pig health. The use of load cells under feed bins to obtain day-to-day measurements of feed disappearance has been introduced. This has been successful in predicting growing performance.
- *Facility throughput:* The number of pigs marketed per pig space per year is a good measure of the efficient use of the facility and the capital required. Clean-out strategies can be compared and monitored.
- *Feed costs per pig:* This index is a combination of feed costs and feed efficiency. It is a strong index to use to justify the minimization of feed costs and can be calculated relatively easily if other indexes are calculated.

Record-keeping in growing-finishing barns is evolving to allow rapid use of records along with prospective estimates of performance. This will continue to be important in the development of the growing-finishing industry. There are a variety of details that can be useful in diagnosing problems and potential performance on individual farms. They can include the following:

- *Gender*: It is well recognized that gender does have an effect on performance and should always be recorded to provide some guidance as to the expected performance of the pig or population of pigs.
- *Weight of culls and mortality:* This is important to accurately define calculations such as average daily gain and feed conversion. These pigs have contributed to the performance and should be included in many of the calculations.
- *Changes in pig weight over time:* In many cases, it is important to identify the time period during which suboptimum growth occurs. Recording a proportion of the pig's weights during incremental periods after the pigs enter the barn is useful in identifying problem areas and, more importantly, predicting the marketing schedule.
- *Weights of individual pigs:* In many cases, not only is the average pig weight important to identify—the distribution of weights is as well. It is important to differentiate in cases of suboptimum growth whether a proportion of pigs or the general population is affected. This can aid in

differentiation of causes and can identify strategies to alleviate the problems.

- *Carcass characteristics:* Since the objective is to produce a lean pork product with a minimum amount of feed, the marketable characteristics of the pigs are important to know. This analysis can identify methods of management, especially comparing groups or ages of pigs.
- *Feed disappearance and costs:* This variable is self explanatory but often poorly measured, especially when rations are mixed on-farm. Recording load cells should be considered in some of these applications.
- *Abattoir surveillance of lesions at slaughter:* If available and possible, every effort should be made to determine the nature and severity of lesions present in pigs sent to slaughter. The incidence and nature of the lesions may reflect the disease status in the herd and assist in the diagnosis, treatment, and control of clinical and subclinical disease. The relationship between the prevalence of lesions at slaughter and environmental factors in the herd is complex and extremely variable. The relation among certain diseases, their lesions at slaughter, and daily weight gain can be estimated.

Chronic diseases certainly have a negative effect on weight gain. Some environmental factors may be associated with certain diseases such as tail biting, but there may be no relation between certain infectious diseases and environmental factors that might be expected to be predisposing. This illustrates the complexity of relating managerial and environmental factors to disease.

The slaughter inspection system in Norway reveals that in bacon pigs, the thoracic cavity is the most commonly affected part of the body because of the frequent occurrence of pleuritis, pericarditis, and pneumonia. Arcoptic mange and ascariasis are also common. In culled sows sent to slaughter, there is a higher incidence of pyemia and abscesses than in bacon pigs. Pyemia and abscesses occur in bacon pigs, often in combination with tail lesions, severe pneumonia, and anemia. Pyemia is also associated with polyarthritis and lesions of the claws. There is a strong relation between serositides and pleurisy, pericarditis, and peritonitis, which suggests that these diseases may be caused by the same agent.

Other studies found a positive correlation among the rates of respiratory disease in feeder pigs, the incidence of clinical disease, the mortality, and the prevalence of lesions at slaughter (Willeberg et al, 1984). Meat inspection appears to be a more sensitive surveillance method for respiratory disease than clinical observation of the pigs. The monitoring of pigs at slaughter is an inexpensive method for obtaining extensive information on clinical incidence, prevalence at slaughter, seasonal and age incidence, efficacy of treatment, and, possibly, the effects of disease on live weight performance and carcass evaluation. It is a powerful tool for the clinico-epidemiological study of some of the common infectious diseases of growing and finishing pigs.

Examination of swine carcasses at slaughter is a valuable aid in several areas of health management. It can be used to detect the presence of subclinical disease or to assist in determining the causative agents of complex diseases. It can also be used to monitor the effectiveness of disease control and therapeutic strategies by comparing the prevalence and the severity of lesions at slaughter before and after implementation of a change between control and test groups (Straw et al, 1986a). Routine slaughter checks also provide a monitoring system to detect subclinical disease that may not have been observed clinically (Miller and Carlton, 1996).

Slaughter checks are valuable for monitoring the prevalence of disease over a wide geographic area and the variations of disease according to seasons. The five major reasons for condemnation of either portions or whole pork carcasses in 1 year were ascariasis, adhesions, abscesses, bruising, and arthritis. These lesions are associated with management-responsive diseases, which are diagnosed at slaughter and account for over 75% of all carcasses condemned.

The logistics of performing slaughter checks have been described (Straw et al, 1986a). The veterinarian must be well prepared for the examination, have the necessary equipment and recording forms, make appropriate arrangements with the producer and the abattoir, and plan which pigs and tissues will be examined and sampled. Careful consideration must be given to the selection of an appropriate number of animals from each different environment in the herd so that the findings will be representative of the real disease situation in the herd. Statistical analysis of the variability of pneumonia and turbinate atrophy suggests that 30 is the minimum number of animals necessary to accurately reflect the level of disease in the herd (Straw et al, 1986a). Positive identification of the pigs from the herd under study is essential. The seasonal variations in disease occurrence must be considered when selecting times of the year for slaughter examinations. When slaughter examinations are made only once or twice yearly, it is possible to miss peaks of disease that occur between the examination intervals. The practical diagnostic procedures used in slaughter checks have been described (Straw et al, 1986b). The speed at which the slaughter line moves varies considerably, and in some cases it moves so quickly that not every pig's lungs can be examined. Lungs are examined and scored primarily for pneumonia and pleuritis, the snouts are examined for turbinate atrophy, and the reproductive tracts can be examined for evidence of diseases of the ovaries and uterus. The stomach is examined for evidence of gastric ulcers, and the liver is examined for evidence of ascarid migration.

The value of a routine slaughterhouse check program for individual commercial producers was examined from seven herds over a period of 4 years in New York State (Straw et al, 1994). Quarterly checks were performed in February, May, August, and November. Pigs were examined for pneumonia, pleuritis, AR, and ascarid infestation. Pneumonia was most severe in pigs slaughtered in the spring, followed by, in descending order, the fall, winter, and summer. AR and ascarid lesions were most severe during the summer and least severe in pigs during the winter. In most cases, there was no evidence of a change in severity of respiratory disease in the herds over the 4-year period. The severity of pneumonia appeared to decrease in one herd whose facilities were extensively renovated. The severity of ascarid scarring decreased in two herds, which instituted control procedures. Commercial producers who made no changes in deworming practices or facilities gained no additional information from repeated slaughterchecks. Thus it is difficult to justify frequent slaughterchecks for most commercial producers unless the checks are accompanied by implementation of new control procedures. Seed stock producers could benefit from routine slaughterchecks as a means of verifying the health status of a herd for potential buyers.

In Finland, slaughterhouse data have been used in herd health management programs organized by cooperative slaughterhouses, and various aspects of the data have been examined using epidemiological studies (Tuovenin, 1994). Slaughterhouse data were compared between farms with high or low levels of condemnations and correlated with environmental and managemental factors in those herds. In feeder pigs units, partial carcass condemnations increased with increasing herd size, increasing stocking density, and increasing ammonia concentration (Tuovenin et al, 1992). Partial carcass condemnations were mainly due to arthritis (50%) and abscesses (35%) (Tuovenin et al, 1994c). The

provision of unsolicited advice to producers about the effects of partial carcass condemnations on average daily gain and production and their relationship to monitored environmental and management factors which was found to be unrewarding (Tuovenin et al, 1994a). It seems that advice can be offered only if requested by the producer and that producers with the greatest need for advice seldom request it. The prevalence and geographical variation of some economically important swine diseases in farrowing units, especially infectious diseases that could be transmitted to the finishing units with delivered growing pigs, was examined (Tuovenin et al, 1994d). Most finishing units received pigs that were infected with mange; the probability of importing pigs infected with the erysipelas pathogen was high. Based on serological studies many herds were positive for *A. pleuropneumoniae* and some for *M. hyopneumoniae.* In Finland, most market pigs are raised in AIAO finishing units. Given the prevalence of infectious diseases in farrowing units, the risk of spreading infectious diseases to finishing units is high. Feeder pigs from one farrowing unit can end up in several finishing units. A system of evaluating the health of farrowing units for freedom from clinical evidence of diseases such as AR, swine dysentery and mange, and seronegativity of colostrum samples for *M. hyopneumoniae* has been described and evaluated (Tuovenin et al, 1994b). The objective is to develop a health classification of multisource feeder pigs for finishing units. A premium price would be paid to the farrowing units to strive for health classification status. Most of the results favored health classification. The benefits were improved daily weight gain, decreased mortality, significant decrease in the incidence of lesions of pneumonia, and pleurisy at the slaughterhouse. Enzootic pneumonia, AR, and swine dysentery were effectively controlled. Enzootic pneumonia is controlled under this system by reducing the risk of infection. Such control procedures minimize the need for the use of prophylactic antimicrobials in the feed. Partial carcass condemnations were higher in the high classification group compared with the control group because of a higher incidence of joint infections.

A survey of the noninfectious factors associated with lung lesions in slaughter pigs from 150 randomly selected farrow-finish pig herds in Belgium found a median herd level prevalence of 24% for pneumonia, 16% for pleuritis, and 60% for lymphohistiocytic infiltration (Maes et al, 2001). Lesions of pneumonia were negatively correlated with lesions of pleuritis. The prevalence and severity of lesions of pneumonia were increased by a high frequency of purchasing gilts and by a slaughtering in January to February. The presence of a growing unit on the farm increased the severity of the pneumonia. The prevalence and the severity of lesions of pleuritis were higher when there were more pig herds in the municipality, when there were inadequate biosecurity measures, and when the slaughtering occurred in March to April. An increase in the airspace stocking density in the finishing unit also increased the prevalence of pleuritis. Pigs raised in pens with slatted floors were also at higher risk of more severe lesions of lymphohistiocytic infiltration.

Diseases of Growing and Finishing Pigs

The most economically important diseases of pigs during the growing-finishing period are infectious diseases of the respiratory and digestive tracts (Losinger et al, 1998b). Raising of pigs in total confinement has successfully controlled several soilborne infectious diseases, but pneumonia and enteritis still occur clinically and subclinically and cause major economic losses. Pigs affected with acute pneumonia are relatively easy to detect. The major problem, however, is the presence of the subclinical pneumonias, such as enzootic pneumonia caused by *Mycoplasma* spp. and pleuropneumonia caused by *A. pleuropneumoniae.* The important diseases of the pig during the growing-finishing period are those that are endemic and cause subclinical disease and those that cause epidemics of clinical disease. Box 15-6 lists the diseases that occur with an indication of how commonly they occur and whether they are usually endemic or cause epidemics.

Respiratory Diseases of Growing and Finishing Pigs

Respiratory diseases are common in swine herds worldwide and are clinically manifested primarily in growing and finishing pigs. The most prevalent are pneumonia, pleuropneumonia, pleuritis, and AR, often with multiple contributing infectious agents. An important risk factor in these diseases is that the primary source of the infections is an infected pig. The causes of economic loss are significant and due to reduced growth and feed efficiency. The economic losses are more severe if respiratory disease occurs early in life or is aggravated by other infectious diseases or an adverse environment. In general the morbidity of these diseases is high, although the mortality is variable depending on the causative agents involved and the level of management and adequacy of the environment in which the pigs are housed.

The effects of each of the diseases just described on growth rate are different on each farm, probably because of differing environments and variations in the virulence of serotypes. The presence of pleuropneumoniae in the herd warrants an evaluation of the epidemiological determinants on each farm, followed by recommendations based on an analysis of the conditions on each farm.

Outbreaks of acute respiratory disease in finishing pigs are a major problem in finishing barns, and their etiology is often unclear. A detailed clinical and diagnostic laboratory evaluation of affected pigs in 16 outbreaks of acute respiratory disease in finishing pigs led to a definitive diagnosis in only 12 (Loeffen et al, 1999). Seven were due to an infection with influenza virus and *A. pleuropneumoniae*. A combination of influenza virus and *A. pleuropneumoniae* may have caused one other outbreak, but no clear cause could be established for the other three outbreaks.

The animal welfare aspect has been examined, and public health concerns with regard to the syndrome have been raised. The use of antibiotics for the treatment of pneumonia in finishing pigs increases the risk of antibiotic residues in carcasses with lung lesions as compared with those without pathological abnormalities. In addition, the environmental factors causally related to respiratory disease in housed pigs may also be a source of health problems in people working on pig farms.

Various methods have been used to control respiratory disease in swine herds. The use of SPF herds has been effective as a method of eradication; however, many of these herds became reinfected at a later stage because of airborne disease transmission. Besides eradication, various control methods designed to reduce infection pressure within the herd, such as management and environmental changes, medication, and vaccination, have been applied with variable success.

Enzootic Pneumonia. Enzootic pneumonia is a bronchopneumonia primarily caused by *M. hyopneumoniae,* and secondary pathogens such as *P. multocida* are commonly the cause of secondary pneumonia. AR, characterized by turbinate atrophy, is caused by some strains of *B. bronchiseptica,* with or without the dermonecrotic toxin-producing strains of *P. multocida.* Pleuritis is associated with infections by *Mycoplasma hyorhinis, P. multocida, A. (Haemophilus) parasuis* and *A. (Haemophilus) pleuropneumoniae.* Pleuropneumo-

BOX 15-6

Diseases of Growing and Finishing Pigs

RESPIRATORY DISEASES

Common

Enzootic pneumonia caused by *Mycoplasma* spp.; commonly endemic
Pneumonic pasteurellosis caused by *Pasteurella* sp.; commonly a result of enzootic pneumonia
Pleuropneumonia caused by *Actinobacillus (Haemophilus) pleuropneumoniae*; endemic and epidemic

Less Common

Atrophic rhinitis (i.e., turbinate atrophy) caused by toxigenic isolates of *Pasteurella multocida* and *Bordetella bronchiseptica*; endemic
Swine influenza; sporadic
Glasser's disease; sporadic

GASTROINTESTINAL DISEASES

Common

Esophagogastric ulcers (e.g., gastric ulcers)
Intestinal helminthiasis; endemic
Ileitis caused by *Lawsonii intracellularis*
Ascariasis resulting from *Ascaris suis*

Less Common

Swine dysentery caused by *Brachyspira hyodysenteriae*; endemic and epidemic
Adenomatosis complex; endemic and sporadic acute clinical illness
Proliferative hemorrhagic enteropathy
Enteric salmonellosis; sporadic
Rectal strictures; sporadic

Rectal Prolapses

Predisposing causes of rectal prolapses include zearalenone toxicosis, chilling (and piling), and genotype. Treatment is usually through replacement and retention using a purse-string suture. It should be noted, however, that many rectal prolapses may be cannibalized and not noticed by the stockperson. Rectal prolapses may lead to rectal strictures.

Torsion of Abdominal Organs

Predisposing causes include agitation, overcrowding, whey rations, and engorgement. At necropsy, the main signs are hemoperitoneum, rotation of the spleen with stomach, enlargement of the spleen, and torsion of the root of the mesentery.

SEPTICEMIAS-SPORADIC

Streptococcus suis
Salmonellosis
Eryisipelas
Hog cholera
Pasteurellosis
Eperythrozoonosis

DISEASES OF THE NERVOUS SYSTEM

Pseudorabies
Str. suis

NUTRITIONAL DEFICIENCIES

Mulberry heart disease, hepatosis dietetica, exudative diathesis caused by vitamin E or selenium deficiency; sporadic
Osteodystrophy caused by absolute deficiency or relative imbalance of calcium and phosphorus; uncommon
Parakeratosis (e.g., zinc deficiency)

GENETIC DEFECTS

Porcine stress syndrome and pale soft exudative pork; common in some herds

BEHAVIORAL VICES—COMMON

Tail biting, ear chewing, flank biting

SKIN DISEASES

Greasy pig disease (*Staphylococcus hyicus*)
Sarcoptic mange

POISONINGS

Salt, arsenic, organophosphate
Selenium
Monensin toxicosis*
Mycotoxicosis (Fumonisins *[Fusarium moniliformis]*)† and vomitoxin

DISEASES OF THE FEET AND MUSCULOSKELETAL SYSTEM

Leg weakness, osteochondrosis; common
Sore feet, cracked feet, foot rot; less common
Erysipelas arthritis; common to sporadic
Mycoplasma arthritis; sporadic

*From Miskimins DW, Neiger RD: *J Vet Diagn Invest* 8:396-397, 1996.
†From Guzman RE, Casteel SW, Rottinghaus GE, Turk JR: *J Vet Diagn Invest* 9:216-218, 1997.

nia, a pulmonary necrosis accompanied by pleurisy, is a frequent consequence of infection with *A. (Haemophilus) pleuropneumoniae*. Acute forms of pleuropneumonia are associated with high-mortality fibrinohemorrhagic pneumonia, epistaxis, and blood-stained fluid in the pleural cavities and trachea.

M. hyopneumoniae is a problem mainly when in concert with secondary bacteria such as *P. multocida*. This pathogen is common among swine herds, although differences in the pathogenicities of strains occur. There are four capsular serotypes: A, B, D, and E; A and D are the most common types, with type D being associated with AR and type A with pneumonia. Both appear to require an initiating pathogen to allow colonization; *M. hyopneumoniae* is thought to be the major initiator for pneumonia, and *B. bronchiseptica* for AR. In AR, there is blockage of the tear ducts, twisted nose, turbinate atrophy, and poor growth rates. In acute pneumonia, clinical findings include dyspnea, productive coughing, some nasal discharge, and a fever of 104° to 106° F. Chronic cases show some productive coughing and poor growth.

Pleuritis occurs occasionally and causes a more severe reduction in growth rates. Both cause uneven growth and overall poor performance, with large amounts of money being spent on its control. It also limits the ability to move and mix pigs.

A comparison of the performance of pigs reared in AIAO production with pigs in continuous flow (CF) production during the growing-finishing phase found that lung lesions were less prevalent and severe in the AIAO system, even though the pigs may have been infected with *M. hyopneumoniae* and *P. multocida* but not exhibited signs of clinical disease when placed in the growing-finishing facility at 17- to 20-kg body weight (Scheidt et al, 1995). Antimicrobials were not added to the rations. The incidence of disease was much higher in the CF pigs than in the AIAO pigs. This illustrates that control of the environment and the population of pigs as a unit allows for improved performance of the pigs, even though they may be infected with the common pathogens causing respiratory disease in growing-finishing pigs.

The effect of enzootic pneumonia on the functional status of the pig has been evaluated by comparing average daily gain and feed efficiency in pigs with pneumonia against those without lesions of pneumonia (Morrison et al, 1986). Since the disease was first characterized, it has been accepted as a major cause of decreased productivity in finishing pigs being fed for market. There are many reports in the literature claiming that the economic losses are the result of mortality from secondary bacterial pneumonia, decreased rate of gain, and increased marketing of undersized or cull pigs. In pigs located at a central performance test station, the presence of lung lesions at slaughter was associated with a decrease in mean daily weight gain. For every 10% increase in the amount of lung tissue affected with pneumonia, mean daily weight gain decreased by 5.3% (Straw et al, 1983). Of the pigs examined at slaughter, 8.5% had no evidence of pneumonia, 52% had pneumonia in 1% to 5% of the lung, 22.5% had pneumonia in 6% to 10% of the lung, 8.5% had pneumonia in 11% to 15% of the lung, and 3.5% had pneumonia in 16% to 20% of the lung. There was involvement of more than 20% of the lung in 5% of the pigs.

These statistics illustrate the large percentage of pigs that may be affected with subclinical pneumonia and the potential for large economic losses as a result of suboptimum performance. The methods used to estimate the economic costs of pneumonia in swine herds include measurement of the growth rate and feed conversion, along with assessment of the severity of pneumonia in the herd, as determined by lesions present at slaughter (Straw et al, 1989). On average, mean daily gain decreased by 37.4 g for every 10% of the pig's lung affected by pneumonia. However, the results of many examinations of the association between enzootic pneumonia and performance have been inconsistent (Morrison et al, 1986). The effect that the lesions of enzootic pneumonia may have on performance depends on management and environmental conditions. Of 23 studies, 10 reported no significant effect, and the remaining 13 reported decreased average daily gain or increased feed:gain ratio by 5% to 25% and 4.6% to 25%, respectively. These variable results may occur because of the different experimental designs and techniques used. Inconsistent results may also be the result of the lung's ability to resolve pneumonia. As pigs increase in body weight above 40 kg, the prevalence of pneumonia decreases. Therefore, in the assessment of pneumonia in pigs at a slaughter weight of 100 kg, the older pigs may have been reduced in their gain; however, if pneumonic tissue has resolved, the pneumonia score may not reflect the true influence pneumonia has had on growth rate. *M. hyopneumoniae* causes a dry, nonproductive, "barking" cough in growing pigs. It predisposes pigs to secondary bacterial infections; independently, there is little effect on production, although it has been associated with decreased growth rates (Beskow et al, 1998).

Enzootic pneumonia in feeder-pig herds is more severe in herds that have inadequate facilities and in which pigs were purchased from auction marts, compared with herds that have good facilities and in which the pigs originated directly from breeding herds. In herds that obtained pigs directly from breeders, the management was considered acceptable and pigs had fewer clinical signs, the fewest pneumonic lesions, the best feed efficiency, and the lowest level and prevalence of the antibodies to TGE. The best evidence suggests that infection of the respiratory tract combined with environmental stressors such as inadequate ventilation and overcrowding causes clinical and subclinical pneumonia.

Actinobacillus Pleuropneumonia. *A. pleuropneumoniae* is the cause of actinobacillus pleuropneumonia. There are at least 13 distinct serotypes (1-12 with 5a and 5b). Certain serotypes are recognized in particular parts of the world, with serotypes 1 and 5 dominant in North America and serotypes 2, 3, and 9 in Western Europe. An excellent review of the taxonomy and bacteriology of the organism is available (Rycroft and Garside, 2000). The organism may cause disease independent of other respiratory pathogens and causes severe necrosis and hemorrhage in the lung of nonimmune pigs. In the acute form, pigs have labored breathing, are profoundly depressed, and die quickly. Lesions may be present throughout the lung but are most common in the upper lung. Necrotic, raised areas are commonly present with a fibrous exudate on the surface. In chronic cases, these necrotic areas become hardened and pleural tags develop. Mortality and morbidity rates can reach almost 100%. The laboratory diagnosis is usually obvious.

Antibiotic therapy, vaccination, and test-and-slaughter programs, either alone or in combination, have been used in attempts to control pleuropneumonia with varying degrees of success. Survivors of acute infection often develop chronic lung lesions and become carriers. The organism does not persist in the environment, and only pigs are known to be susceptible to infection; therefore elimination of the organism seems feasible. The infection is spread between herds by carrier pigs that harbor the organism in the nose, tonsils, or is sequestered in the lungs without any clinical sign. The spread of the disease is difficult to control because there is no reliable method to determine whether or not a pig herd is infected. The distribution of the serotypes varies from country to country, and the relative virulence of each serotype also varies (Vaillancourt et al, 1990). Three serological tests are available: namely, the modified complement fixation test, the ELISA test, and the 2-mercaptoethanol tube agglutination test. The immune response is serotype specific, but some serotypes share antigenic determinants with other serotypes. This may complicate both serodiagnostic and seroepidemiological work.

The disease occurs most commonly during the winter months in Canada, when the temperatures are cold for long periods and the adverse weather conditions commonly lead to poor ventilation of barns. Other important risk factors include increased traffic of pigs into the herd, purchasing of supplementary stock from sales barns rather than from herds known to have a low prevalence of the disease or from one breeder, and crowding of pigs.

The economic impact of the disease depends on the morbidity, mortality, treatment costs, and its effect on growth rate, feed efficiency, and carcass condemnations, all of which are dependent on the virulence of the serotype. In some herds the morbidity and case fatality from pneumonia can be high, whereas in others, the disease is subclinical and can

be identified only serologically and by the presence of lesions of pleuritis at slaughter. The effect of the disease on growth rate and feed efficiency varies from herd to herd and may be influenced by the level of management. In some herds, the incidence and severity of the disease can be controlled at acceptable levels by improvements in management and the treatment of clinically affected pigs.

Long-acting oxytetracycline IM may prevent experimental infection (Kiorpes et al, 1989) and may reduce mortality if used early in the course of the disease. However, the organism has developed resistance to certain antimicrobial agents. There is a high prevalence of resistance to ampicillin, penicillin, chloramphenicol, and tetracycline (Vaillancourt et al, 1988). When comparing the effectiveness of different treatments, the veterinarian must know exactly the virulence of the strains involved as well as their drug sensitivity. If this is not possible, eradication using depopulation and repopulation may be necessary.

A less inexpensive method of control is successive depopulation, in which seropositive sows are culled when their pigs are weaned at 3 weeks of age. These piglets, which are protected by colostral immunity and are unlikely to be infected, are then reared in isolation from potentially infected stock. During the period of elimination of the sows, the feed may be medicated for 6 to 12 months to inhibit the spread of the organism.

Pigs surviving a natural infection develop immunity and are protected against further infections of homologous or heterologous serotypes. However, the antigens that produce this solid protective immunity have not been identified clearly, and commercially available vaccines based on whole-killed bacteria do not provide complete protection. The success of the vaccines has been limited because of irregular efficacy, cost, short duration of immunity, and development of injection site granulomas. Piglets vaccinated with an inactivated tetravalent vaccine against serotypes 1, 2, 5, and 7 produced antibodies after the first injection and an anamnestic response after the second (Rousseau et al, 1988). This suggests that a second vaccination before sending piglets to the finishing unit should help to reduce the losses caused by pleuropneumonia.

Atrophic Rhinitis. The effect of atrophic rhinitis on growth rate and feed efficiency is inconclusive (Cowart et al, 1990; Scheidt et al, 1990). Turbinate atrophy assessed at the abattoir was not related to growth rate; however, in a few herds, pigs with severe turbinate atrophy had slower growth rates. In other studies the average reduction of growth rate in pigs with severe turbinate atrophy was 4.7% compared with pigs without it (Baalsrud, 1987). The difference was significant only in some herds. Pigs with moderate turbinate atrophy gained on average 1.1% less than unaffected pigs. There was no relationship on a herd basis between the reduction in growth rate and the percentage of pigs in the herd with the disease. The economic losses caused by atrophic rhinitis in a herd may be estimated on the basis of the number of pigs affected. As finishing pigs gain about 1 kg/day during the immediate preslaughter period and are slaughtered at approximately 100 kg of live weight, pigs with moderate atrophy need about 1 more day to compensate for the 1.1% reduced growth rate; those with severe atrophy require about 5 more days to reach normal slaughter weight.

The relationship between turbinate atrophy and pneumonia is variable. In some studies there was no difference in the prevalence of pneumonic lesions at slaughter among pigs with turbinate atrophy (Straw et al, 1983).

Whereas infectious atrophic rhinitis is caused by toxin-producing *P. multocida* types A and D and *B. bronchiseptica*, and the presence of the former can produce a severe progressive form of the disease, there is much variation in the severity of the conchal damage seen both within and between farms where both pathogens are present. The mere presence of the organisms is not a sufficient cause for the disease to occur. The aerial environment is considered an important part in the epidemiology and pathogenesis of the disease. Inflammation and colonization of the nasal mucosa occur in the young pig. Atmospheric ammonia, dust, and microbial concentrations in the farrowing house, as well as dust in the stage-one weaner house, play a significant role in the severity of the disease.

There are significant and positive correlations between the severity of conchal atrophy at commercial slaughter weights and the increased aerial concentrations of dust, bacterial counts, and ammonia in farrowing houses. The relationships between the dust concentrations in the first-stage weaner houses and the severity of the disease at slaughter were stronger and more numerous than the relationship with the farrowing houses. Some farms have a relatively low average snout score of conchal atrophy even though the toxigenic pathogens are present, which emphasizes that air quality has an important mediating role in the expression of clinical signs of the disease. Air quality can be influenced by the management and design of a building and the fixed equipment in it, and the severity of the disease can be influenced by manipulation and control of air quality.

Swine Influenza. Swine influenza is classically caused by virus type H1N1. The virus enters a herd and spreads rapidly by aerosol, with almost 100% morbidity with fever, dyspnea, and some coughing. Recovery occurs in 5 to 7 days with little or no mortality unless secondary infections occur. In comparison with other respiratory diseases, there are minimal clinical effects unless secondary infections occur.

Systemic Diseases. Several diseases, including those caused by *S. choleraesuis, A. suis, Str. suis,* and *H. parasuis,* can cause a bacteremia with localization in the lungs, resulting in pneumonia. This is particularly the case in the presence of preexisting lesions of *M. hyopneumoniae.*

Epidemiology of Respiratory Disease in Growing and Finishing Pigs

The risk factors that predispose to respiratory disease in growing-finishing pigs are complex and multifactorial. It is often difficult to interpret the significance of the presence of pathogens in the tissues of affected animals. The literature on the epidemiological investigation of the influence of environmental risk factors on respiratory diseases in swine has been reviewed (Stark, 2000). These factors can be categorized as characteristics of the herd, the management, the air quality, and the neighboring farms. The large number of factors associated with respiratory diseases and their interaction make it difficult to understand the epidemiology.

From a practical basis the factors can be divided into those affecting the presence of a causative agent known as infection pressure, and those that influence the susceptibility of the individual animal and consequently the establishment of the disease.

Infection Pressure. Nose-to-nose contact and airborne route are the most common routes of transmission. Transmission between animals requires (1) excretion by infected animals, (2) critical concentration, and (3) contact between susceptible animals and the causative agent. Because causative agents are easily introduced into a farm with live animals, the purchase policy of a farm is one of the most important risk factors. Generally, closed farms have the lowest risk, whereas exclusively finishing farms that purchase all their pigs are at highest risk, especially if they buy from several sources or from an auction market. The probability of purchasing infected pigs increases with

multiple sources, as the number of pigs purchased increases, and as frequency of purchasing increases (Stark, 2000). Finishing farms that purchase all of their stock are at greater risk than breeding farms, which are less likely to buy large numbers of animals from different sources.

Airborne transmission of infectious agents occurs from infected to noninfected animals within farms, and between neighboring farms if they are close enough. After their release from infected animals, infectious agents can exist as airborne or nonairborne particles. Certain management procedures can be used to reduce the concentration of infectious particles in the environment and to reduce the risk of a susceptible animals coming in contact with the agents. For airborne particles, the number of pigs sharing the same air space in a building, the stocking density, and the air volume available per pig are factors influencing aerosol levels. Ventilation also has a direct influence on aerosol levels and is associated with respiratory disease (Stark, 2000).

As herd size increases, the risk of respiratory disease increases. The presence of nearby swine farms with respiratory disease also increases the risk.

For nonairborne particles, other management factors are important. Production systems in which pigs are moved through the different production stages in batches (AIAO) compared with CF systems generally include cleaning and disinfecting steps that reduce pathogen concentrations. The literature on this subject indicates that it is highly advantageous for the control of respiratory disease.

Environmental Risk Factors and Susceptibility of the Pig. Several factors are considered to affect the susceptibility of pigs to respiratory disease (Stark, 2000). The microclimate of the environment is characterized by temperature, humidity, dust, gases, and airborne bacteria. Temperature and air drafts are the main sources of climatic stress. The immune response of pigs experimentally challenged with *A. pleuropneumoniae* may be affected by drafts and fluctuating temperatures. Air temperature and humidity have a close relationship to each other, but their combined effects to increase the susceptibility of pigs to respiratory disease are not clear. The survival of airborne respiratory pathogens depends on air humidity, and the number of respirable particles is also related to air humidity. Airborne gases, dust, and pathogens are also important components of the microclimate affecting susceptibility. Dust, ammonia, carbon dioxide, and microbes are correlated with the occurrence of pneumonia and pleuritis at slaughter. In behavioral studies, pigs exhibit distinct preference for fresh air compared with ammoniated air (100 ppm). This emphasizes the importance of environmental monitoring to ensure an optimum climate for pig production and a healthy environment for swine confinement-building workers.

Management risk factors influencing airborne particle concentrations include stocking density, ventilation, use of bedding, manure disposal, and method of feeding. Slatted floors and inadequate floor insulation (no bedding) may contribute to respiratory disease, but their effects have not been quantified. Similarly, the effects of floor feeding and access to drinking water may be involved but have not been evaluated. Changes in the weather may influence the occurrence of respiratory disease; it may be more common during cold wet seasons.

Host risk factors that may increase the susceptibility of pigs to respiratory disease include the immune status of the animals, the presence of other infectious diseases, nutritional deficiencies, and the presence of toxic factors such mycotoxins in the feed (Stark, 2000). The age of the pigs at weaning and birth weight may also be related to the severity of pneumonic lesions at slaughter. There also may be an association between the social status of the pig and its immune response (Hessing et al, 1994). Dominant pigs have significantly higher values in a lymphocyte proliferation assay than subdominant and subordinate pigs. Regrouping of pigs after weaning is an acute stressor.

A well-designed epidemiological analysis of the effect of environmental factors on the health of finishing pigs is recorded by Lindqvist (1974). Clinical inspections were made in 99 finishing herds involving 209,815 pigs delivered for slaughter over a 3-year period. The study attempted to answer several important questions about the role of housing and environment on the health and production of finishing pigs.

The average daily gain in pigs with severe pneumonia at slaughter was significantly lower than that in pigs without lung lesions at slaughter. There were no differences in growth rate between pigs with mild pneumonia as the sole pathological lesion and those without lung lesions at slaughter. The incidence of pleurisy and pericarditis was also lowest when pigs were housed in sections of less than 500 pigs, when production was strictly in batches, and when the total area was more than 0.7 m^2/pig. The incidence of pleurisy was highest during the warm period from May to October, and the average daily gain was lower in pigs with pleurisy than in those without pleural lesions at slaughter.

In an overall assessment of the results, it was concluded that health status generally appears to be better in barns with production strictly in batches, less than 500 pigs/section, space volume of at least 3 m^3/pig, a total area (e.g., lying area and area in dunging passage) of at least 0.7 m^2/pig, a solid manure-handling system in the house, and free access to drinking water. It also was concluded that, of the studied environmental factors, the system of rearing has the greatest influence on animal health.

It was evident that an assessment of health status based entirely on observations made at slaughter must be complemented by a veterinary assessment of the animals in their environment during the period of production if definite conclusions are to be drawn. If this is not done, essential information on the general clinical condition and behavior of the animals will be absent, as will be data on diseases that are not recorded at slaughter.

In another field study, a microcomputer-based environmental monitoring system was used to continuously monitor temperature, relative humidity, bacterial colony count of the air, and ventilation rate in commercial growing-finishing barns (Bauck et al, 1990). Significant differences existed among barns for daily maximum and minimum temperature, relative humidity, ventilation rate, and average bacterial colony-forming particle counts. There was no difference among farms in the average percentage of lung affected with pneumonia, average snout atrophy score, or growth rate of the test animals. It seems that further work is necessary to define measurable environmental parameters that may be responsible for variations in respiratory disease and productivity or that could be used as indicators of other environmental factors that affect disease and productivity (Bauck et al, 1990).

Factor analysis has been used to describe risk factors for respiratory disease on pig farms (Hurnik et al, 1994a). Factor analysis is a statistical technique for condensing the information from a large number of variables into a small set of uncorrelated new variables called factors that are weighted sums of the original variables. Under favorable conditions, each of the original variables is correlated highly with a single factor. These correlations induce a partition of the original variables into groups of correlated variables, each group being associated with a single factor. Subsequently these factors can be used as predictor vari-

ables in regression models. From the examination of 76 farms, 43 management variable were calculated. The 43 variables were condensed into 6 factors through factor analysis. The farm types that emerged were as follows: (1) smaller farms using extensive farming techniques: high volume and space per pig and straw as bedding, (2) a farm type using group flow, a system that used solid pen partitions, did not move pigs between pens, and a higher ratio of pigs to water spaces, (3) a farm type with room pig flow that was larger (pigs sold) than others in the study population, was farrow-to-finish, and had modern facilities, (4) farms that bought pigs from different sources, did not seek veterinary advice, and had slow-growing pigs, (5) a family farm type that primarily floor fed the pigs, and (6) an integral farm type that was larger than average, made its own feed, was closer in proximity to other farms, and had other farmers as primary visitors.

The results of the factor analysis can then be used in a regression analysis of enzootic pneumonia and pleuritis prevalence at slaughter (Hurnik et al, 1994b). Farms were dichotomized on enzootic pneumonia prevalence greater or less than 10%. Multiple source feeder barns (Farm Type 4) with low emphasis on disease entry and control had an odds ratio of 2.38 of having enzootic pneumonia. Family farms (Farm Type 5) using floor feeding methods had an odds ratio of 3.31. Integrated farms (Farm Type 6) had an odds ratio of 2.31, suggesting that farms that mill their own feed and are closer in proximity to other pig farms have a greater chance of having enzootic pneumonia. A linear regression of the prevalence estimates of enzootic pneumonia on positive farms revealed that only farms with multiple source feeder barns and floor-fed family farms were associated with a higher prevalence of enzootic pneumonia. Farms with extensive pig housing (Farm Type 1) were associated with a lower prevalence, suggesting that farms with ample pen space and air volume had fewer pigs with enzootic pneumonia. The odds of pleuritis were also lower on farms with extensively housed pigs. In summary, the study demonstrates that certain combinations of management risk factors found on the pig farms examined are associated with an increased overall risk of having enzootic pneumonia.

Simulation modelling can be used to predict the prevalence and severity of respiratory disease and the economic effects in relation to environmental factors. One such program is RESPIG, in which the air quality on a farm is classified into one of six categories; then the disease process is simulated along with its effect on feed intake, feed conversion, and growth (Turner et al, 1993).

In summary, the epidemiology of respiratory disease in growing and finishing pigs is complex, an investigation of respiratory disease requires a systematic identification and evaluation of the risk factors before recommendations can be made about which changes are necessary to control the disease and its effects on production. The critical aspects that should be examined include the following:

- *Hygiene:* Cleaning, disinfection, fly and rodent control, animal and person traffic, vehicles
- *Husbandry:* Climate, feeding, installations (pens effluent system, troughs, ventilation)
- *Management:* Stocking density, purchase policy, animal movements within a farm

Control of Respiratory Disease in Growing and Finishing Pigs

The control of respiratory disease in growing and finishing pigs depends on the prevention of infected animals being introduced into the herd and on the provision of adequate housing and ventilation. One environmental risk factor that may affect the health of growing pigs in intensive housing systems is the atmosphere, which includes air temperature, air movement, humidity, noxious gases, dust particles, and aerial bacteria (Jansen and Feddes, 1995). Other risk factors are related to the pens, including divisions in the pens, flooring, dunging facilities and disposal methods, feeder space allowance, and stocking density. Other factors include hygiene and the presence of pests as possible vectors.

If pneumonia is a major problem in a finishing barn, it may be possible to alter up to 20 environmental variables in an attempt to reduce the incidence of disease (Done, 1991).

1. A minimum of 250 to 300 pigs per barn (ideally 150).
2. Only 10 to 12 pigs in a pen, preferably with no mixing or moving.
3. More than 3 m^3 of air space/pig.
4. At least 0.7 m^2 of lying and dunging areas/pig with at least 0.5 m^2 for lying.
5. An AIAO policy should be operated.
6. Only one source of piglets to the finishing system.
7. The pens should be cleaned and disinfected between groups.
8. The number of air changes per hour should be increased.
9. A solid manure system is preferable.
10. If a slurry system is used, the slurry ideally should be removed daily to prevent accumulation of toxic gas.
11. The temperature fluctuations should be kept to a minimum.
12. Single span buildings are best because they help minimize cross infection.
13. Air should flow from the lying to the dunging area and then out the building.
14. Ammonia levels should be kept below 20 ppm and hydrogen sulfide below 10 ppm; other potential gas hazards should be reduced by segregating the pigs from the stored slurry.
15. Dust levels should be kept as close as possible to outside levels (1 mg/m^3) and not allowed to exceed 10 mg/m^3.
16. The level of respirable dust (0.5 to 2.5 μ) should be kept as low as possible by attention to feeding and bedding techniques.
17. Bacterial levels should be kept below 10^4 m^3 by attention to stocking densities and cleanliness; filters may become necessary.
18. Gram-negative organisms should be kept at low levels to reduce the aerial concentration of endotoxin, probably by efficient manure removal and cleanliness.
19. The pigs should have free access to drinking water.
20. Most important, attention should be paid to stocking densities, particularly during the winter months.

The principles of control of the major respiratory diseases of growing and finishing pigs are summarized here. The general control of respiratory disease depends on which respiratory disease is most prevalent in the herd. More than one of three common diseases may be present, which will require the development of a control strategy to meet the needs of the particular herd.

Enzootic Pneumonia. *M. hyopneumoniae* infects only pigs, and transmission requires close pig-to-pig contact. If transmission can be prevented, it is possible to limit or even eradicate the disease from a herd. There are thus two levels at which control can be practiced: *complete eradication* or *controlling the disease and its effects at a low level.*

The principles of control of enzootic pneumonia include the following strategies:

- Regular inspection of the herd for evidence of disease clinically and use of slaughter checks of lungs.
- Rigorous biosecurity of animals being introduced into the herd and control of visitors.

- Provision of adequate environmental conditions, including air quality, ventilation, temperature control, and stocking density.
- Use of the AIAO system of production, in which groups of pigs by age or stage of production are moved through the herd from the gestation barn, farrowing barn, nursery rooms, finishing units, and the pens previously occupied are cleaned, disinfected, and left vacant for several days before animals are reintroduced.

Eradication. This method of control is the most satisfactory and is probably mandatory for large breeding companies and herds supplying replacement stock to other herds and for large intensive farrow-to-finish enterprises. It is based on the principle that the source of infection for the young pig is the gilt or the sow, and this chain of infection must be interrupted to prevent infection.

SPECIFIC PATHOGEN FREE OR MINIMAL DISEASE PIGS. Several methods of eradication have been attempted, but the most satisfactory is repopulation with SPF pigs. The principle underlying this method is that the piglet in utero is free of infection with *M. hyopneumoniae.* If it is taken from the uterus at term by suitable sterile hysterectomy or hysterotomy techniques and reared artificially in an environment free of pigs, it will remain free of this infection. In practice this has been done in special units and the piglets have been used subsequently to repopulate existing farms where all pigs have been removed 30 days before the SPF pigs were introduced and a thorough cleaning program completed. This method was initially developed for the control of enzootic pneumonia and atrophic rhinitis. Moreover, if suitable precautions are taken and if the piglets are used to populate new units that have had no previous exposure to pigs, freedom from other important diseases such as internal and external parasitism, leptospirosis, brucellosis, swine dysentery, and others can be achieved. The progeny of these primary SPF herds can be used subsequently to repopulate other or secondary SPF herds known as minimal disease pigs.

Because of the cost and technical difficulty of this method, other methods of eradicating enzootic pneumonia have been attempted, but they are generally less satisfactory and have a higher failure rate. These include *"snatching" of pigs at birth* and *isolated farrowing*. In the former the piglets are caught and removed from the sow immediately at birth and reared as previously described or foster-suckled on SPF sows in another environment. Although enzootic pneumonia may be eliminated by this method, fecal contamination during parturition of the vulva and vagina and consequently of the piglet is common; this method is less satisfactory for disease control than removal by hysterectomy.

ISOLATED FARROWING. Isolated farrowing techniques have proved successful in small herds but have a high failure rate when practiced on a large scale. Older sows believed to be free of infection are farrowed in isolation in individual pens erected outside on pasture, and each sow and litter is kept as a separate unit. The litter is inspected clinically at regular intervals, and subsequently a proportion of the litter, usually excess males and gilts undesirable for breeding, are examined at slaughter for evidence of pneumonia. Any litters with clinical, pathological, or laboratory evidence of pneumonia are eliminated from the program. Litters that pass inspection are kept for repopulation of the herd. Because of the difficulties in detecting carrier pigs without lesions, eradication by methods using these principles frequently fails.

MINIMAL DISEASE HERDS. Minimal disease herds have been established in most countries with significant pig populations either by breeding companies or private purebred breeders. As a result there is, in most countries, a nucleus of enzootic pneumonia-free stock, which is a major swine-producing enterprise worldwide. The establishment of primary SPF herds is technically difficult and very costly and should not be undertaken lightly. There is also a considerable delay in cash flow between the time of initial population and buildup of herd numbers to the time when significant numbers of pigs are available for sale. Because of this, if eradication by repopulation is intended, it is preferable to purchase pregnant gilts from established primary SPF herds unless the maintenance of existing genetic lines dictates otherwise. Before recommending eradication by this method, the pig owner must understand the principles of this method of control and the restrictions that will need to apply if it is to be successful. Farrow-to-finish enterprises established by this method should be run as closed herds, and if further genetic material is required it should be introduced by hysterectomy techniques or by purchase from the initial source herd. The use of AI is an alternate method; however, isolation of *M. hyopneumoniae* from semen is recorded.

The problem of certifying and maintaining herds free of enzootic pneumonia is a major task.

Reinfection of herds. Reinfection of enzootic pneumonia-free pig herds occurs despite high standards of isolation and strict precautions, whereby complete protective clothing and showering routines are required for all visitors entering the unit. All visitors are debarred entry if they have been to a possible source of infection during the previous 48 hours and even up to 7 days. Also, the majority of breakdowns occur in herds that have not imported infected stock recently. In reinfected herds that imported stock, there was no concurrent evidence of breakdown in the parent herds, which supported the contention that the importation of infected pigs was an unlikely source of the infection. An epidemiological investigation of these reinfections suggests that close proximity of uninfected herds to infected herds may be an important factor. The organism does not survive for more than a few days under dry conditions; however, it can survive in diluted tap water and rainwater for 2 to 3 weeks, and it has been suggested that the organism may be transported in moist air and that airborne infection between piggeries is a possible method of transmission. Some preliminary estimates of risk indexes based on the proximity of other pig units has indicated that the most important factor was the reciprocal of the square of distance to the nearest other unit. The crucial distance for maximum survival was about 3.2 km.

Antimicrobial prophylaxis. Eradication of newborn piglets has been attempted by antimicrobial treatment with oxytetracycline on Days 1, 7, and 14, followed by weaning on Day 14 and a move to an offsite nursery. This is known as a low-cost, modified, medicated-early-weaning program. This can be followed by serological testing of the breeding herd and culling of positive reactors. Antibiotics are of questionable value, although tetracyclines, tiamulin, lincomycin, and tylocin have been used. Vaccines are being produced and have been shown to reduce the level of lesions at slaughter (Maes et al, 1999).

Low-level disease. The alternative to eradication is to limit the effects of the disease in those herds in which eradication is either not desirable or not feasible. The effects of the disease are generally less severe in nonintensive rearing situations and in small herds in which individual litters are reared separately and in which litters from older sows can be reared separately from other pigs. Where litters are grouped at weaning, a low stocking density with less than 25 pigs in initial pen groups and 100 pigs in a common air space may also reduce the severity.

Temperature, humidity, and ventilation also have an important influence on the disease. It is possible to determine an optimum air temperature zone for growing-finishing

pigs based on the measurement of behavioral and health-related problems. They are interrelated with stocking density and housing. The subject is too broad for full explanation here, and the requirements for pigs at different ages and under different housing situations may be found in standard texts on pig housing and production. The environmental risk factors associated with the incidence of enzootic pneumonia should be assessed in each circumstance. Some important environmental variables that should be assessed and modified include: the number of pigs per shed; the number of pigs per pen; the air space per pig; the floor space per pig; the cleaning and disinfection techniques used; the number of air changes per hour; the waste disposal system; the number of temperature fluctuations in a 24-hour period; the direction of the flow of air in the building; the concentrations of ammonia and hydrogen sulfide in the building; the dust levels; the feeding and watering systems; and whether or not the AIAO system is being used effectively.

Medication of breeding stock. The original medicated-early-weaning program was based on medication of the sows with tiamulin at the time of farrowing and the early weaning of the piglets to an off-site location. A variation of this method is to prevent the spread of infection by isolation of the breeding stock, strategic antimicrobial medication of the breeding stock, reintroduction of the breeding stock to the original but empty and disinfected gestation barn, separate rearing of the piglets before and after initiating the program, and regulation of flow of animals through the herd. Farrowing barns are emptied out when possible, and cleaned, disinfected and left empty. After weaning their piglets, sows are transferred to the dry sow barns. Sows about to farrow are treated with tiamulin and moved to the farrowing barn.

Source of feeder pigs. Where possible the purchase of weaners or pigs for finishing units should be from herds free of the disease or from a single source. Purchase through saleyards or the purchase of coughing or uneven litters is not advisable. When pigs from infected herds are purchased, it may be necessary to medicate the feed prophylactically with one of the tetracycline group of antibiotics or tylosin or spiramycin at 100 to 200 mg/kg of feed for a 2-week period after introduction. Medication of the feed of finishing pigs with tiamulin at 20 and 30 mg/kg of feed over an 8-week period on farms with histories of severe complicated enzootic pneumonia led to improved weight gains and feed efficiency, but the extent and severity of the lung lesions did not change. The level of 30 mg/kg in the feed was superior to the level of 20 mg/kg. Tiamulin at 100 mg/kg, combined with chlortetracycline at 300 mg/kg of feed for 7 days, was effective in herds with a history of enzootic pneumonia complicated by the presence of *P. multocida* and *A. pleuropneumoniae*.

Introduced pigs should be isolated from the rest of the herd and preferably reared as a batch through a house on the AIAO system. A high stocking density should be avoided, and internal parasites should be controlled.

Immunization. Vaccination with killed *M. hyopneumoniae* induces protection in pigs against experimental challenge exposure with the organism. A killed *M. hyopneumoniae* vaccine evaluated in a single herd reduced the prevalence of pneumonic lesions in slaughter pigs from 69% to 36% and the prevalence of pleuritis from 20% to 13%. There was a small decrease in the number of days to market. Other limited studies indicate that vaccination can reduce the severity of lung lesions detected at slaughter (4% to 6% compared with 12% in controls), improves feed efficiency and increases average daily gain during the finishing period. In other studies the average daily gain was not improved.

Actinobacillus Pleuropneumonia. There are two options for the control and prevention of porcine pleuropneumonia: (1) control at an economical level using good management combined with the possible use of vaccines, and (2) eradication of the infection from the herd. Determining which option to select requires careful consideration of the advantages and disadvantages of each option. With an understanding of the factors that result in clinical disease, it is possible to maintain an infected breeding herd and to produce pigs with a small risk of clinical disease.

Management. Control is difficult and unreliable because pigs that recover from clinical disease provide a source of future infection for finishing operations that purchase all of their introductions. The AIAO system of purchasing, feeding, and marketing pigs, with a thorough cleaning between groups of animals in a finishing operation, should be adopted. The disease is highly contagious, and control measures must be directed toward identifying and eliminating infected pigs into uninfected herds. When pigs are moved between herds, it is critically important that the herds be matched according to their infection status. Source herds for feeder animals are serotested, and then pigs of like immune status are commingled to produce a population that is immunologically compatible. By commingling only animals from seronegative herds, the risk of disease is greatly decreased and growth performance improved. The mixing of animals from herds known to be infected with homologous serotypes is also effective.

Every economical effort must be made to identify and isolate infected pigs and to exclude the importation of clinically normal but infected pigs into herds in which the infection is not present. This is a major challenge that is dependent on the availability of a highly sensitive and specific laboratory test. The acquisition of new breeding stock for herds free of the infection should include a period of quarantine and two serological tests 3 weeks apart. Only seronegative animals should be introduced into the herds. A seropositive animal should be considered a potential carrier. Field trials have shown that it is not possible to rear seronegative animals within a breeding and rearing herd heavily infected with serotype 2 of the organism. Neither medication of the sows and piglets with trimethoprim-sulfonamides nor a strictly applied AIAO system reduced the percentage of seropositive animals.

Management practices must emphasize the rearing of weaned pigs in pens separate from older stock, which are carriers of the organism. Large breeding herds and finishing units should subdivide the total herd into separate units, which minimizes the spread of infection. Early weaning and segregation of gilts from infected stock have been used to develop a seronegative herd.

Herds can be classified into one of three categories depending on their infection status:

- *Category 1:* Serologically positive for *A. pleuropneumoniae* without a history of clinical disease. A majority of herds are serologically positive but do not have clinically apparent disease. Good management and environmental quality control can minimize the incidence of clinical disease. Good ventilation, the use of AIAO management practices, and appropriate stocking densities are important.
- *Category 2:* Serologically negative and clinically free of *A. pleuropneumoniae*. These herds can be maintained free of infection with good biosecurity practices. New breeding stock must be obtained from herds free of infection. AI can be used to limit the introduction of live pigs. Pigs sold from these herds to herds with endemic infection are highly susceptible to infection.
- *Category 3:* History of clinical disease caused by *A. pleuropneumoniae*, which has been pathologically and microbio-

logically confirmed. In these herds, acute disease outbreaks occur most commonly in pigs 9 to 20 weeks of age. Pigs are usually protected by colostral immunity for the first 8 weeks of life. The severity of outbreaks can be reduced by mass medication of the feed, treatment of individual pigs, and good management practices to ensure adequate ventilation.

Eradication. Recurring outbreaks of pleuropneumonia is the most common reason for an eradication strategy. Eradication is achieved by depopulating the entire herd, followed by repopulation with animals from herds that are clinically and serologically negative. Eradication can be successful but the risk of introducing infections into the herd are high unless biosecurity measures are adopted and strictly implemented.

An alternative to depopulation is medicated early weaning in which pigs are weaned at 10 to 15 days of age, treated with antimicrobials, and reared in isolation. Transmission of infection between the sow and piglets does not occur before 11 days of age; about half of the piglets are infected at 16 days of age, and if weaned at 21 days of age most of the piglets are infected.

The early weaning program can be expanded to the three-site system of rearing. Adults and nursing piglets are housed in one site. At weaning, piglets are moved to the nursery barn for growth to 25 kg and then moved to a third site for the final growing period. The adults may be serologically positive for infection, but the nursery pigs and growing and finishing pigs are negative.

Age segregation, distance that prevents aerosol transmission, and adherence to strict biosecurity practices can reduce the prevalence of infection and the incidence of disease.

Vaccination. Natural or experimental infection with a serotype of *A. pleuropneumoniae* induces a strong immunity to both homologous and heterologous serotypes. Vaccination has been attempted to prevent pleuropneumonia in pigs. However, the protection obtained by parenteral vaccination is serotype specific, and vaccines must therefore contain the serotype existing in the swine population. The mortality rate is lower in vaccinated animals, but they are still carriers of the organism.

Serotype 8 is closely related to serotypes 3 and 6, and parenteral revaccination using a capsular extract or killed *A. pleuropneumoniae* serotype 8 provides a high degree of protection against challenge with serotypes 3 or 6. A tetravalent vaccine containing serotypes 1, 2, 5, and 7 stimulated titers to all four serotypes, and an anamnestic response was induced by a second vaccination This suggests that the serological and cross-protective properties of *A. pleuropneumoniae* serotypes should be identified before they are used as antigen in the complement fixation test and in vaccines.

Atrophic Rhinitis. Control of atrophic rhinitis can be attempted in at least four ways: *total eradication, reduction of infection pressure, mass medication with antimicrobials to reduce the severity and adverse effects of infection,* and *vaccination.*

Regardless of the method used, any effective control program must have a system for monitoring the incidence of clinical disease in the herd and the incidence and severity of turbinate lesions of the pigs sent to slaughter. Accurate and reliable methods for monitoring clinical disease are not available, but the incidence of acute rhinitis and facial deformities could be recorded regularly. At slaughter, snouts can be examined for lesions of turbinate atrophy and for assessing a mean snout score for each group of pigs slaughtered.

Total Eradication. Total eradication can only be achieved with confidence by complete depopulation for a 4-week period and repopulation with primary or purchased SPF stock. This approach has the added advantage of eliminating enzootic pneumonia, which may be a significant contributing factor to the economic importance of this disease. However, this method of control is extremely costly, and the economic importance of the disease would need to be carefully evaluated in relation to this cost before this method was instituted. Other techniques of obtaining pigs free of atrophic rhinitis, such as the isolated farrowing of older and presumed noncarrier sows with subsequent clinical and postmortem examinations of a proportion of the litters, have had a significant failure rate in the field and are not recommended. Eradication by repopulation with cesarean-derived stock may be essential in breeding nucleus herds in which a high generation turnover leads to a low herd sow age and a low herd level of immunity. The breakdown rate of herds established by this method can be significant, presumably because the initiating organisms are not solely confined to pigs.

Reduction of infection pressure. Reduction of infection pressure can be attempted. Infection of piglets occurs primarily either from carrier sows or from other infected piglets in the immediate environment, and severe atrophic rhinitis generally results from infection of piglets under 3 weeks of age. If these factors can be minimized, the incidence and severity of the disease can be reduced. An AIAO pig flow is one of the most effective methods for control of atrophic rhinitis. A change to an AIAO pig flow from continuous flow management can improve snout scores by 50%, lung scores by 55%, average daily gain by 0.14 lb, and days to market by 13 days.

Since severe lesions depend on infection of the piglet under 3 weeks of age, every attempt should be made to minimize the severity of the challenge to young piglets. It is a common observation that the effects of atrophic rhinitis are minimal under good systems of management and adequate ventilation, nondusty conditions, and good hygiene. The use of continual throughput farrowing houses and weaner houses allows a buildup of infection, with the presence of actively infected pigs that can provide a high-infection pressure on piglets born into or introduced into these areas. The use of AIAO systems of management in these areas is recommended, and young piglets should be kept in a separate area from older pigs.

Mass medication. The prophylactic use of antimicrobials reduces the incidence of the disease within the herd. Antimicrobials are used both within the breeding herd to reduce the prevalence of carriers, and in young suckling and weaner pigs to reduce the severity of the infection. The medication is begun about 2 weeks before farrowing, continued throughout lactation, and incorporated in the creep feed for the sucking pigs and the starter feeds for the weaned pigs. In this way there is continuous medication of the sow and the piglets during the most susceptible period. For the breeding herd, sulfamethazine at levels of 450 to 1000 mg/kg feed, with the higher levels being given to dry sows on restricted feeding, has been recommended. Sulfonamide resistance has proved a problem in some countries, but beneficial results may still be achieved with these levels. It is recommended that medication be continued for a 4- to 6-week period. Carbadox at 55 ppm in combination with sulfamethazine at 110 ppm is reported to be effective in clearing experimentally induced *B. bronchiseptica* infection; when used alone, it improved growth rate and feed efficiency in pigs with naturally occurring atrophic rhinitis. In the starter period, carbadox fed alone or in combination with sulfamethazine improved average daily gain in piglets from herds with naturally occurring atrophic rhinitis. Use of the medication, however, did not lead to a reduction of mean nasal lesion scores resulting from atrophic rhinitis. Sulfamethazine at 110 mg/kg of feed is more effective than sulfathiazole, at the same concentration, for the control of experimentally in-

duced atrophic rhinitis resulting from *B. bronchiseptica*. Sulfamethazine may also be incorporated in creep rations, and the use of tetracyclines (200 mg/kg of feed), tylosin (50 to 100 mg/kg of feed), and penicillin (200 mg/kg of feed) have also been suggested.

Medicated early weaning is recommended to obtain pigs free from pathogens, including *B. bronchiseptica*, that are endemic in the herd of origin. The sows are fed medicated feed from 5 days before to 5 days after weaning, and the piglets are dosed from birth to 10 days of age.

Vaccination. There has been considerable interest in the development of vaccines for the control and prevention of atrophic rhinitis resulting from *B. bronchiseptica*. Inactivated vaccines have been used to vaccinate the pregnant sow 4 to 6 weeks before farrowing and, in some cases, followed by vaccination of the piglets at 7 and 28 days of age. In general, the use of the vaccine in pregnant sows in herds in which the disease has been endemic has reduced the incidence of clinical atrophic rhinitis. However, the results from one study to another have been highly variable. Vaccination of the pregnant sow does lead to an increase in colostral antibody titer, which does improve the clearance rate of *B. bronchiseptica* in the piglets. However, it has been difficult to evaluate the efficacy of the *B. bronchiseptica* used alone, because the turbinate atrophy caused by infection of piglets with *B. bronchiseptica* experimentally or naturally heals and regenerates completely when they are reared to about 70 to 90 kg body weight in good housing conditions.

Gastrointestinal Diseases of Growing and Finishing Pigs

Unlike respiratory diseases, enteric diseases in growing pigs are usually due to a single agent, and the control is directly related to that agent. However, the occurrence and significance of gastrointestinal diseases in growing pigs has been decreasing with the use of AIAO production (Paul et al, 1997). In a recent U.S. study, enteric diseases accounted for 13.6% of mortality in growing-finishing pigs, and 9.5% in a U.K. study (Pearce, 1999). In addition, chronic enteric diseases have been suggested to increase feed costs by at least 50%.

Epidemiology. The epidemiology of enteric disease in growing-finishing pigs was examined using a mail questionnaire (Pearce, 1999). Enteric diseases causing diarrhea are a significant problem in growing-finishing pigs in the United Kingdom, with more than 50% of producers reporting a problem at some time during the previous 3 years. The survey found significant associations between several management factors and the occurrence of diarrheal disease in growing-finishing pigs (Pearce, 1999). All the important enteric pathogens of pigs are spread by the fecal-oral route, and control measures depend on reducing environmental contamination by adequate cleaning and disinfection between pens of pigs. Less than 40% of producers used disinfection as part of routine practice. The use of disinfectants in the preparation of pens between batches of pigs appeared to be protective (odds ratio of 0.3). Approximately 47% of producers used some form of isolation procedure for incoming breeding stock, which compares with 50% and 63% of producers in the United States who isolate new female and male breeding stock, respectively (USDA:APHIS:VS, 1995).

The use of slatted floors for finishing pigs was associated with a 3.6-fold increase in the risk of diarrheal disease. This may be due to inadequate cleaning of slatted floors and increased residual fecal contamination, which promotes the spread of disease between batches of pigs.

The use of a wet feeding system for finishing pigs was associated with a 5.9-fold increase in the risk of enteric disease, which may be related to less than satisfactory standards of hygiene.

The practice of tail-docking piglets was associated with an 8.6-fold increase in the risk of diarrhea in growing-finishing pigs. This may be due to a common link between poor environmental conditions and the increased levels of environmental stress known to be involved in mediating both the occurrence of tail biting (and the attempts to prevent it by tail-docking) and the incidence and severity of enteric diseases such as proliferative enteropathy.

Intestinal Spirochetal Infections. Intestinal spirochetes cause two well-recognized diseases in pigs: swine dysentery and intestinal spirochetosis. A third disease, spirochetal colitis, is less clearly defined but is caused by weakly β-hemolytic spirochetes other than those causing intestinal spirochetosis (Hampson and Trott, 1995).

Swine Dysentery. Swine dysentery is caused by *B. hyodysenteriae* and is characterized clinically by dysentery. The organism, found almost exclusively in pigs and rodents, proliferates in the large intestine, causing degradation of the surface and secretion of mucus and blood. Signs include diarrhea, sometimes involving blood with a rapid loss of condition, depression, and dehydration. Lesions are limited to the large intestine with necrotic debris coating its surface. There are dramatic reductions in weight, especially if left untreated, and mortality can occur in 1 to 2 days. Treatment is through antibacterial therapy via feed, water, or injection. Prevention is through sanitation and separation of affected pig. Elimination of the disease can be made through a combination of sanitation and medication (Harvey, 1997).

Intestinal Spirochetosis. Intestinal spirochetosis is caused by *Serpulina pilosicoli* sp. nov., which has a broad host range including human and nonhuman primates, pigs, dogs, commercial chickens, and various species of wild and zoo birds. The disease affects pigs between 4 and 20 weeks of age and is characterized clinically by mucus containing nonbloody diarrhea, poor feed conversion, and depressed growth rates. PCR assay can be used to differentiate *B. hyodysenteriae* from *Brachyspira pilosicoli*, both of which cause diarrhea in growing and finishing pigs (Barcellos et al, 2000). A detailed review of intestinal spirochetosis in swine is available (Hampson and Trott, 1995).

Porcine Proliferative Enteritis. *Lawsonia intracellularis* (ileitis, porcine proliferative enteritis, porcine intestinal adenomatosis [PIA]) causes proliferation and degradation, primarily of the mucosa of the ileum. It is found in all ages of pigs after weaning but is most common in 60- to 120-lb pigs. The disease is often sporadic but leads to poor performance in affected animals. The direct financial losses resulting from the disease are considered high (McOrist, 1997; McOrist et al, 1997). The use of PCR assays to detect the organism in intestinal mucosal samples is highly sensitive (Jordan et al, 1999). The test may be an appropriate monitoring tool for swine herds because it is a rapid procedure that could be applied to batch testing. Treatment and prevention is usually performed through the use of antibiotics, almost all of which are efficacious (McOrist et al, 1997). Continuous in-feed medication with chlortetracycline at 300 or 600 ppm can prevent disease in pigs challenged with *L. intracellularis* (McOrist et al, 1999).

Salmonellosis. *Salmonella* infections cause economic losses in the swine industry. In the United States, *S. choleraesuis* accounts for 90% of clinical cases of swine salmonellosis characterized by septicemia, pneumonia, hepatitis, and death. This disease is often a result of immunosuppressive factors such as chilling or PRRS. Most outbreaks also involve cases of sudden death with no diarrhea; these pigs characteristically have discolored ear and abdomen. Bloody diarrhea is a common sign in conditions that are more chronic. The

combination of mortality and depressed growth rate can be expensive and can affect 50% of a group by depressing growth rates and feed conversions. Antibiotic treatment is often unsuccessful. Prevention through the control of predisposing factors is preferred (Cole et al, 1994). *S. choleraesuis* is only rarely a zoonosis.

S. typhimurium primarily causes enterocolitis and is an important cause of human foodborne illness. Pigs leaving the farm are considered the main source of abattoir contamination by *Salmonella*. Pigs represent an important reservoir of *Salmonella* spp. and can spread the bacteria throughout the abattoir environment.

The prevalences of *Salmonella* spp. and *Y. enterocolitica* in finishing pigs examined at slaughterhouses in Canada ranged from 4.0% to 6.4% and from 18.8% to 23.0%, respectively (Letellier et al, 1999b). Overall, 24.6% of the animals tested were positive for one or both these pathogens. Only a small proportion of herds (2.8%) appeared to be contaminated by *Salmonella* spp. Other surveys of the prevalence of *Salmonella* contamination of pig carcasses found 28% in Greece, 17.5% in Canada, 21% in the Netherlands, and 27% in Belgium (Davies et al, 1999). In a sampling of a large number of pigs in an abattoir in the United Kingdom, salmonella was isolated from 7.0% of carcasses and 11.6% of samples of large intestinal contents (Davies et al, 1999). *S. typhimurium* DT 104 was found in 3.2% of the large intestinal samples. Sequential sampling during the slaughter process found 83% of the carcasses contaminated after bleeding, a percentage that was reduced to 5.7% after scalding eliminated after singeing. *Salmonella* infection was present in the pigs from 45% of farms and on a third of farms; *S. typhimurium* DT 104, a multiple antibiotic resistant strain, was present. The DT 104 strain and other multiresistant phage types have also been isolated from Danish pig herds, but the prevalence is low (Baggesen and Aarestrup, 1998).

Carrier pigs are positive for *Salmonella* in mesenteric lymph nodes, tonsils, colon, or feces, and development of control measures to reduce fecal or lymph node carriage of *Salmonella* in live animals would be an important step in the reduction of this pathogen in meat products. Pigs are a significant reservoir of foodborne pathogens such as *Salmonella* and *Yersiniacolitica*, and the mass production and rapid distribution of food poses a risk for widespread foodborne outbreaks resulting from these pathogens. The scalding and singeing processes used in the slaughter of swine, if properly conducted, can reduce the level of contamination of the surfaces of carcasses of salmonella to minimal levels before evisceration. The spillage of material from the intestinal tract, mainly as a result of intestinal perforation during evisceration, is the major source of carcass contamination.

On finishing pig farms previously identified as contaminated by *Salmonella*, sampling of the environment found the organism in fecal material in pens, doors, floors, ventilation units, dust, and farm accessories (Letellier et al, 1999a). The prevalence and distribution of *Salmonella* spp. in breeding herds supplying finishing pigs to finishing units was determined. The overall prevalence was estimated at 7.9%. Among the farms sampled, 70% were positive for *Salmonella* spp., and the distribution of infection was 15.9% in replacement sows and 21.9% in the finishing unit for gilts. The demonstration of vertical transmission of *Salmonella* spp. at different levels of integrated production system stresses the importance of reducing carriage in live animals by very strict and constant farm hygiene measures, starting at breeding farms, combined with other measures.

The management of manure and hygiene are very important in controlling salmonella infection in finishing units. Housing of finishing pigs on solid concrete floors with open-flush gutters increases the risk of salmonella shedding compared with housing on slatted concrete floors. Recycled lagoon water is commonly used to flush effluent from beneath slatted floors or from open-flush gutters. Compared with using fresh water for flushing, flushing with recycled effluent reduces total effluent output from a herd but provides a potential vehicle for transmitting organisms shed in feces or urine.

Although *Salmonella* can survive in liquid and solid pig manure for several months, *Salmonella* concentrations in fresh effluent are higher than in waste stored in anaerobic pits. Achievement of frequent and effective removal of feces from the flush gutters by increasing the frequency or volume of flushing with recycled liquids may be as effective in controlling *Salmonella* transmission as substituting recycled effluent with fresh water for flushing (Davies, 1998). Facilities should be designed to enable effective removal of fecal material from pens to control *Salmonella* in barns with open-flush gutters. When constructing facilities with open gutters, care should be taken to design gutter volume, gradient, and flush volume to ensure effective removal of feces from all pens.

On-farm initiatives in food safety, such as the HACCP, help reduce the risk of foodborne transmission of pathogens. Various treatments to reduce carriage of *Salmonella* in swine have been evaluated (Letellier et al, 2000). The use of some probiotics and prebiotics can alter the composition of the gut microflora to the benefit of the host (Letellier et al, 2000). A reduction of *Salmonella* in the colonization of mesenteric lymph nodes occurred with the use of bambermycins and a live attenuated vaccine (Letellier et al, 2000). The strategy of competitive exclusion cultures to enhance the colonization resistance of early-weaned pigs to *S. choleraesuis* has some potential based on some preliminary experimental work (Anderson et al, 1999).

Healthy pigs can carry *Salmonella* in their intestines and may shed this pathogen because of stresses incurred during transportation, contaminating trailer floors and bedding material. If not cleaned and sanitized between trips, trailers and bedding have the potential to infect other farms, the abattoir environment, or other animals with the organisms. *Salmonella* can be isolated from up to 80% of the bedding material in trailers. Up to 42% of trailer floor samples may be positive for *Salmonella* before washing, and 2.7% positive after washing and sanitizing. Neither distance traveled nor season of the year influences the number of *Salmonella*- or *E. coli*-positive pig trailers. Washing and sanitizing of pig-hauling trailers between loads to reduce or eliminate the incidence of *Salmonella* is effective (Rajkowski et al, 1998).

Feed and feed trucks may be sources of *Salmonella* contamination (Fedorka-Cray et al, 1997). The sample prevalence of *Salmonella* in feed trucks is low (0.7%), the overall contamination rate for feed trucks is much higher (22.7%), and thus feed could be a source of *Salmonella* contamination for swine herds.

It is possible to prevent *Salmonella* infection of pigs originating from a heavily contaminated herd by raising them at a distant, clean site (Nietfeld et al, 1998). Offsite growing-finishing strategies provide a management technique along with others such as all-in, all-out production and rigorous cleaning between groups of pigs to help control *Salmonella* infection. Prevention of environmental cycling of *Salmonella* spp. is an important component of a *preharvest food safety program*.

Esophagogastric ulceration. Ulceration of the esophagogastric region of the stomach is a common, widespread cause of mortality condition in finishing pigs worldwide. In some herds, mortality from ulcers can reach 1% or higher, with losses resulting from culling up to 3%. The prevalence of erosions in the pars esophagea of the stomach can range from 32% to 100% (Ayles et al, 1999).

Feeding finely ground pelleted feed to finishing pigs between 25- and 107-kg bodyweight can cause hyperkeratosis of the pars esophagea in 75% to 89% of the pigs with 11% of pigs with extensive erosions or ulceration. Pigs with extensive lesions gained 50 to 75 g/day less weight than pigs with no lesions in the pars esophagea (Elbers et al, 1995). Several factors involved in its pathogenesis have been recognized. The gastric ulceration characteristic of this problem occurs in the pars esophagea region of the stomach. This area often becomes hyperkeratotic and eroded, and such lesions are seen in many swine at slaughter with no apparent effects on productivity. A proportion of affected swine develops more severe erosions that lead to bleeding. Many of these cases are acute and severe and lead to death because of exsanguination into the digestive tract.

Mortality is generally acute and is usually diagnosed by the fact that the carcass is extremely pale, hence its vernacular description "bleach-out" (Friendship, 1997).

The feed manufacturing industry is faced with a difficult problem: on the one hand, finely ground feed is converted efficiently into growth, but on the other hand, it is associated with the erosion and ulceration of the pars esophagea. Pigs with slight ulcerative lesions of the pars esophagea grow significantly slower than pigs without such lesions. Mild gastric ulcers may cause pigs to take longer to reach market weight, causing an economic loss without clinical signs or mortality. A small dietary particle size has been associated with increased risk of gastric ulcers in pigs. A small particle size (approximately 500 to 600 μm) increases both the severity of and the incidence of gastric ulcers. Dietary melatonin supplementation increases the apparent digestibility of crude protein and dry matter of the diets and decreases the prevalence of ulcers, but it may not affect growth performance (Ayles et al, 1999).

Other factors that may be involved in esophagogastric lesions include the following:

- *Season*: There is an increase in lesions in the summer. This may be caused by temperature changes or concurrent changes in diet or management.
- *Nutritional deficiencies*: Suggested deficiencies have included vitamin E, selenium, and fiber.
- *Stress*: Overcrowding, mixing, and large variations in environmental temperature have been suggested as factors.
- *Disease*: Veterinarians have observed that many pigs that die from gastroesophageal ulcers also have large lung lesions, which are usually caused by enzootic pneumonia.
- *Genotype*: There appear to be differences between genetic lines in the incidence and severity of ulcers.
- *Age*: Farms report that mortality from ulcers occurs at distinct periods after entry into the finishing barn.

The majority of the factors just listed do not occur independently and thus the components of causation are difficult to measure. For instance, hot weather is associated with an increased use of fats in swine diets. Fats in swine diets during warm weather leads to an increased degradation of vitamin E. Also, the hot temperatures may induce greater mould and mycotoxin growth in swine feedstuffs.

Internal Parasites. Nearly all of the most common intestinal parasites of pigs are unevenly distributed among different age groups. *I. suis* and *Strongyloides ransomi* are most common in piglets, *Ascaris suum* and *Trichuris suis* in growing pigs, and *Esophagostomum* spp., *Hyostrongylus rubidus*, and *Eimeria* spp. in adult pigs (Roepstorff et al, 1998).

Surveys of market-age pigs have demonstrated *A. suis* prevalences of up to 60% based on adult parasites and typical liver lesions (Wagner and Polley, 1997). In Saskatchewan studies, sows are the most commonly treated age group, as they are in Australia and Denmark. Weanlings were the second most commonly treated age group, and the least commonly treated were the growing pigs. For anthelmintics to be used efficiently, treatment programs should be based on the epidemiology of the targeted parasites.

Locomotor Diseases of Growing and Finishing Pigs

Diseases of Feet and Legs. Diseases of the feet and legs can be a significant problem in modern intensive swine production systems. The major locomotor problems occur in adolescent and breeding pigs. In breeding stock, locomotor disease is usually only secondary in importance to reproductive inefficiency in the reasons for culling. Locomotor disease is one of the most common reasons for rejection of boars from breeding companies. Osteochondrosis, a noninfectious condition manifested as a failure of endochondral bone formation, is thought to be a principal predisposing cause of leg weakness in pigs approaching breeding age (Nakano et al, 1987). The lesions are most common in the distal humerus, the distal femur, and occasionally in the scapulohumeral and coxofemoral joints. Various factors such as rapid growth rate, lack of exercise, floor types, and dietary minerals and vitamins have been suggested and explored as important causative factors. However, there is no evidence linking any of these factors to the pathogenesis of the lesions. The effect of sow nutrition during lactation on the incidence of the disease in their progeny has been examined (Walker and Aherne, 1988). An increase in the mineral and vitamin intake above National Academy of Sciences–NRC recommendations has no effect on the size of toes, feet, and legs; the incidence and severity of horn and pad lesions; or the overall structural soundness and feedlot performance in crossbred boars from 35 to 330 days on test. Certain types of floors can cause foot lesions, but the effect does not extend to the knee and elbow joints. Osteochondrosis is frequently observed in growing swine fed under normal nutritional and management conditions. From 90% to 100% of pigs at 6 months of age have lesions of osteochondrosis of varying severity without any detrimental effect on growth rate or locomotor ability. These lesions are considered potential causes of lameness in young pigs and mature breeding stock. An advanced degree of osteochondrosis, however, leads to severe lameness, which affects breeding animals. The etiology of osteochondrosis is unclear.

The literature on floor surfaces and flooring materials for pigs has been reviewed (Kornegay and Lindemann, 1984). Differences in the incidence and severity of toe lesions have been reported for different floor surfaces. The lateral toes of the pig's foot, especially the hind foot, are larger, and because of their size they may be more susceptible to injury than are the medial toes (Kornegay and Lindemann, 1984). The desirable floor should satisfy the following requirements:

- The floor should not be the cause of injury—it should be of a nonslip, nonabrasive surface and should not have sharp, exposed, or protruding edges.
- It should not harbor bacteria and parasites by being impervious and readily cleaned.
- The floor should not contribute to stress or discomfort, which might be manifested by depressed growth and poor feed utilization.
- It should be thermally matched to the class of pigs housed on it.
- The floor materials should not deteriorate or deform during their planned life.
- Perforated floors should not retain feces and urine for periods of time, which would require some form of cleaning or scraping.
- Floors should comply with the above requirements at the lowest possible cost and should be comfortable to the pig, easy to keep clean, durable, and economical.

The different kinds of floors available for farrowing crates, weanling pigs, and growing-finishing pigs have been described (Kornegay and Lindemann, 1984). The footing and gait of pigs on different concrete surfaces have been examined. Some studies indicate a higher incidence of clinical disease and a higher mortality rate in pigs housed on punched metal floors than in those on plastic slats (Barrett et al, 1988).

Foot lesions in growing and finishing pigs may be caused by insufficient dietary levels of biotin. There is no requirement for supplemental biotin for weight gain, but a dietary requirement between 50 and 100 mg/kg of diet is indicated to prevent foot lesions.

Porcine Stress Syndrome (Malignant Hyperthermia). This is an autosomal recessive inherited muscle disease to which 10% to 20% of swine are susceptible (O'Brien, 1995). This syndrome can be initiated by a number of stressors including shipping, overcrowding, restraint, and farrowing. Affected pigs are rigid and have muscle tremors and labored breathing. Body temperatures may exceed 44° to 45° C (112° F), and death resulting from heart failure may occur in minutes. The postmortem diagnosis is made through the PSE quality of the muscle. Most susceptible pigs have been estimated to have some of these qualities in their meat at slaughter.

Skin Disease of Growing and Finishing Pigs

Sarcoptic Mange. Sarcoptic mange is an important disease of the skin of growing and finishing pigs but can affect pigs of all ages. It is caused by *Sarcoptes scabei* var *suis* and is characterized by intense pruritus. The mite infects only pigs, and direct contact between pigs is the principal mode of transmission. The presence of mange in a herd can affect growth rate, feed conversion, carcass value, and damage to facilities (from the effects of affected pigs scratching). There is a perception that mange in pigs is not a problem, and many producers either disregard the disease or do not use adequate control methods. Based on abattoir inspection of pigs, the prevalence of infection is widespread (Melancon, 1998). The Papular Dermatitis Lesion scoring system, as part of the Minnesota PigMON standardized swine slaughter monitoring system, was used to survey the presence of skin lesions on slaughtered pigs (Melancon, 1998). The overall prevalence of mange, defined as the percentage of lots of pigs with an average dermatitis score of 0.5 or greater during the evaluation period, was 43% for all lots. The overall prevalence of mange among pigs processed at individual plants ranged from 31% to 53%.

Studies performed in Australia, the United States, Canada, Europe, and Latin America evaluated the associations between *Sarcoptes* infestation and the severity of papular dermatitis at slaughter, using an ordinal scale for classifying carcasses (Cargill et al, 1997). The specificity of localized dermatitis ranges from 75% to 80%, and that of generalized dermatitis is highly specific (>98%).

Of greater importance than the difference in prevalence among the various locations is the fact that sarcoptic mange is still a persistent disease among herds, despite the availability of strategies for establishing mange-free herds such as SEW, herd depopulation and repopulation, and whole-herd treatment programs with effective insecticides. Effective mange-control programs are being either ignored or inadequately applied, which emphasizes the need for educational efforts to more fully elucidate the various effects of subclinical mange infestations.

Eradication programs consist of treating all animals at an interval of 14 days with ivermectin. Simultaneously, the pens are emptied, cleaned, and disinfected. This procedure is effective but laborious and time-consuming, and it may explain why eradication programs have not been done more commonly (Jacobson et al, 1999). The effectiveness of a herd eradication program can be evaluated using an ELISA. Blood samples are taken from all adults and from 20% of piglets aged 10 to 12 weeks, before initiating the control program, every third month during the first year and a final sampling 18 months after the treatments. After successful treatment, the antibodies continuously decline.

Sarcoptic mange was eradicated from a breeding herd using a combination of injectable ivermectin and in-feed ivermectin (Smets et al, 1999). Sows, replacement gilts, boars, and weaned piglets were treated with ivermectin (1% solution) by subcutaneous injection on Days 0 and 14, at a dose of 1 ml/33 kg body weight (equivalent to a minimum of 300 (g ivermectin/kg). Newborn piglets were given 0.27% solution subcutaneously on Days 0 and 14, at a dose of 1 ml/9 kg. Finishing pigs were treated with ivermectin oral powder (0.6%) in the feed over two periods of 7 consecutive days (Day 0 to Day 6 and Day 14 to Day 20). Finishing pigs from 25 to 40 kg were given 2 ppm in the feed, and animals from 40 to 100 kg were given 2.4 ppm. Before the treatment, 28% of ear scrapings of finishing pigs were positive for the presence of mites. Within 1 year after treatment adult animals were negative for mites and the scratching index, previously high, was very low. The feed consumption of the sows decreased by 5%; rebreeding decreased by 4.5%; average litter size increased 0.33 live piglets born/litter; and the farrowing index increased by 0.075 litters/sow/year. The production index increased by 1.34 more piglets weaned/sow/year. The costs of the treatment were recovered within 3 to 7 months.

MANAGEMENT OF ANIMAL HEALTH AND PRODUCTION DURING THE GROWING AND FINISHING PERIODS

The control of the economically important diseases and the management of production of pigs during the growing and finishing periods require a high level of animal-production management and the adoption of disease-control techniques designed for intensively reared animals. Those aspects of management that are most important include the following.

Specific Disease Eradication Policy

Certain diseases, such as enzootic pneumonia and swine dysentery, can be eradicated from the herd by the adoption of SPF or MD herd policy, in which the breeding stock are cesarean or hysterectomy derived. The piglets are not in contact with the sows and are reared in isolation until they reach puberty, when they are transferred to the breeding farm facilities. All breeding stock in the new herd are derived this way, and with strict security precautions, the herd remains free of specific pathogens. In addition test and cull strategies have been successful to eradicate pseudorabies from sow herds. Swine dysentery has also been eradicated by strategic medication of the herd.

In self-contained, purebred, or commercial farrow-to-finish enterprises, the common infectious respiratory and enteric diseases can be controlled satisfactorily by the adoption of techniques designed to prevent entry of disease into the herd and by the provision of an adequate housing system.

All-In, All-Out Production System

AIAO production of pigs during the growing-finishing phase is well established as means of reducing certain diseases and improving growth performance, including improvements in average daily gain, feed intake and feed conversion, de-

creased mortalities, decreased number of culls, and lesions of pneumonia and atrophic rhinitis detected at slaughter. A comparison of the performance of pigs in AIAO production with CF production during the growing-finishing phase found lung lesions that were less prevalent and severe in AIAO pigs (mean severity score, 3%) than in CF pigs (mean severity score, 15%) (Scheidt et al, 1995). The AIAO system is highly economical compared with the continuous flow system.

Every effort should be made to ensure that a previously cleaned and disinfected room or finishing barn is filled at one time with a group of pigs that are reared as a group throughout their growing and finishing periods. If possible, pigs moved from the weaner pens (e.g., nursery) should be maintained as a group and placed in a pen of the same group in the finishing barn. This "pen integrity" minimizes the stress associated with the change in feeding and environment. Some facilities are now maintained as "wean-to-finish" buildings where pigs are reared from weaning until marketing in the same pen (Jacobson, 1998).

Housing Environment and Floor Space Allowance

Confined housing for growing-finishing swine may be provided in the form of completely enclosed, modified open-front, and open-front buildings. Most enclosed buildings are insulated and have mechanical ventilation, auxiliary heat, and partially slatted or solid floors. Modified open-front or curtain-sided buildings rely on natural ventilation, do not have auxiliary heat, and may be open on one side, whereas open-front structures are generally insulated, open on one side, and have feeders and waterers located in outdoor concrete lots.

One of the basic requirements for housing of growing-finishing pigs is a warm, dry, and draft-free environment. Extremes of ambient temperature in the building, excessive air movement, and extremes of relative humidity can adversely affect rate of daily gain, feed consumption, and feed efficiency. In large, densely stocked barns for growing and finishing pigs, it is frequently suggested that the indoor climate causes unsatisfactory growth, respiratory disease, tail biting, and unfavorable hygiene, despite the indoor temperature being within the optimum range. Experimentally, different combinations of air velocities and temperatures can affect the behavior of growing and finishing pigs and lead to pigs' lying in dung areas, variable growth rates, and tail biting (Sallvik and Wallberg, 1984).

It has been estimated that the U.S. commercial swine industry is achieving only 65% to 75% of its genetic potential for growth because of limitations associated with the growing environment. Factors that potentially limit growth include physical (thermal, stocking density, feed and water access), social (pigs per pen, movement), and microbial (sanitation, segregation) conditions that may contribute to physiological and immunological stress. The influence of environment on the growth of commercial finishing pigs has been examined by comparing growth of pigs moved from the nursery to the environments of the adjoining commercial growing and finishing buildings or an unrestricting research environment (Holck et al, 1998). Liveweight, lean, and fat growth in pigs raised in a conventional commercial environment was reduced to 70% of that achieved under less limiting research conditions. Pigs in the unrestricted research environment had a higher average daily liveweight gain, fat-free lean gain, and fat gain compared with pigs raised in the commercial environment. The liveweight gain and lean growth advantage of the unrestricted research group of pigs were immediate and consistent at each measurement. The pigs in the unrestricted environment had lower serum levels of α-1-acid glycoprotein (AGP) and higher levels insulin-like growth factor-1 (IGF-1) compared with pigs in the commercial environment. This suggests that such biomarkers may be useful for monitoring a pig's response to its environment. There is need for field research to better understand the environmental factors limiting pig growth and evaluating cost-effective methods of intervention.

Floor surfaces in swine barns can influence foot health. Surveys indicate that 50% to 60% of pigs examined at slaughter may have foot lesions. Field trials to determine the effect of types of floor slats on performance and certain foot and leg characteristics of growing-finishing swine indicate the complex nature of the effect of floor surfaces. Lack of adequate exercise and hard flooring in confinement-rearing systems are suggested as major contributing factors to leg weakness and osteochondrosis in growing-finishing swine, especially young boars in performance test station. However, placement of affected animals in a pasture only slightly improves their gait. Shortening the length of the performance test period and increasing the opportunity for animal exercise may help to alleviate the problem. The genetic aspects of foot and leg soundness in swine have been examined, and the results are inconclusive.

The design of the pens should provide for adequate floor drainage, easy cleaning, ease of daily inspection of pigs, adequate ventilation, and effective manure disposal. The stocking rate should follow recommended guidelines, which are described below. The locations of the feeders, waterers, and dunging areas must reduce the fecal-oral route of infection. An adequate ventilation system is assumed to be necessary for the control and prevention of infectious respiratory disease.

The amount of floor-space allowance provided for weanling, growing, and finishing pigs can have a major impact on production during those phases of the pig's growth (Kornegay, 1986a; Kornegay and Notter, 1984). The literature on the effects of floor space and number of pigs per pen on performance (Kornegay and Notter, 1984) and stocking density for growing and finishing pigs (Kornegay, 1986b) have been reviewed. To maximize pork production from a given facility, the producer must be aware of the relationship between floor space per pig and individual performance. Individual performance includes daily body weight gain, daily feed intake, and body weight gain:feed intake ratio. Pen efficiency includes daily gain per daily feed intake per square unit of floor space. Within a given range, individual performance of weanling, growing, and finishing pigs decreases as area of floor space per pig is restricted. Insufficient space allowance may adversely affect individual pig performance and welfare, but high building costs encourage increasing stocking densities in commercial swine enterprise. Even though pig producers are very concerned with individual pig efficiency, the efficiency of a given facility is of more concern from an economic standpoint (Kornegay and Notter, 1984).

The floor-space requirements per pig are influenced by the number of pigs per pen, whether the floor is solid or fully or partially slatted, the temperature and air velocity, the pen design, disease control and sanitation level, the use of feed additives such as antimicrobials, the gender of the pigs, the pig behavior, and the use of decking to improve building efficiency (Kornegay and Notter, 1984).

Floor-space allowances have been studied in the United States and England, and similar results were obtained. Space allowance (Am^2) was defined in relation to liveweight (Mkg) of the pigs according to the equation $A = kM^{067}$, using values for the constant (k) of 0.024, 0.027, 0.030, and 0.034. For commercial recommendations, the calculated space allowance (m^2) would be $A = 0.030\ M^{067}$, or 0.6 m^2 for a

90-kg pig. This is appropriate as a guide to the minimum space requirement of 35- to 90-kg pigs when they are kept on fully slatted floors (Edwards and Armsby, 1988; Gonyou and Stricklin, 1998). The smallest space allowance constant of 0.024 is approximately the minimum lying-space allowance specified in current U.K. welfare codes (Ministry of Agriculture, Fisheries and Food, 1983).

The current U.S. floor space recommendations for pigs housed on partially or fully-slatted floors for which maximum daily gains would be expected are 0.38, 0.92, and 1.04 m^2/pig for weanling, growing, and finishing phases, respectively (Kornegay and Notter, 1984).

Pen efficiency (e.g., amount of pork produced per unit of feed in a given amount of floor space), represented by daily gain per daily feed intake per unit floor space, increased as stocking density increased (Kornegay and Notter, 1984). Therefore within reasonable limits, an increase in pig density (e.g., decreasing space per pig) would increase profits for the producer by spreading the costs of facilities over more pigs marketed. As a result, it is common for some producers to practice some degree of crowding in their confinement facilities. In summary, individual pig performance decreases as floor space per pig is reduced, with a much larger effect on feed intake than on feed efficiency. However, pen efficiency improves as floor space per pig is reduced. An increase in the number of pigs per pen with a constant space allowance per pig reduces individual pig performance slightly, but it has little effect on the pen's rate of feed conversion efficiency (Kornegay, 1986a). Smaller pen sizes provide more flexibility to ensure that all pigs in a pen are of uniform size and allow an individual pen to be kept fully stocked, which would lead to better feeding, resting, and dunging patterns (Kornegay, 1986a). An increase in the feeder space for weanling pigs would not overcome depressed daily feed intake caused by increased stocking density. Although the inclusion of antimicrobials in the diets of pigs can improve both the growth rate and the feed efficiency, the feeding of antimicrobials does not compensate for the adverse effects of insufficient space allowance (Zimmerman, 1986). The effects of the antimicrobials and the space allowances are independent.

In intensive pig production, unacquainted pigs are mixed together in pens, and this generally leads to vigorous fighting. An increase in numbers of long-lasting fights has led to decreased feed conversion efficiency, and decreased weight gains after mixing have been found for pigs fed at a restricted level but not for pigs fed ad libitum (Rundgren and Lofquist, 1989). It has been suggested that in group-fed pigs, the effects of fighting might interfere with feed intake because high-ranking pigs usually have more access to the feed trough. Experimentally, the effects of mixing pigs of a mean weight of 23 kg on agonistic behavior and performance indicate found decreased daily weight gains in the period between 23 and 100 kg body weight for barrows, but not for gilts. For gilts, feed conversion efficiency was negatively correlated with the number of attacks during the observation period (e.g., 80 minutes after mixing); for the barrows, feed conversion efficiency was negatively correlated with fighting injury scores (Rundgren and Lofquist, 1989).

Feeds and Feeding of Growing and Finishing Pigs

A comprehensive presentation of swine nutrition is beyond the scope of this book, but some important aspects are mentioned.

The nutrient requirements of the growing and finishing pig are sufficiently well known so that specific nutritional deficiencies should not occur. The qualitative and quantitative nutrient requirements and clinical signs of deficiency or toxicity are given in publication of the NRC (1998). Literature on recent advances in swine nutrition has been published. Veterinarians providing animal health and production management advice must become familiar with the above information and how it is used in order to formulate diets and to detect clinical and marginal nutrient deficiencies.

In a farrow-to-finish operation, feed costs for the growing-finishing phase of the production cycle accounts for 75% of the total feed costs, and 45% to 55% of total costs must be charged to finishing pigs (Kornegay, 1986a). Therefore feed costs per unit of quality pig marketed have a major impact on the cost of production. Feed costs can be reduced by making feed conversion better by improving genetics, improving diet formulation, reducing feed wastage, and providing a more desirable environment. The goal should be to maximize feed intake while minimizing feed costs per unit of pork produced. When swine producers are faced with very narrow profit margins as a result of low pig prices and high production costs, they are often tempted to reduce the amount of protein and mineral supplements they add to cereal grains to make the diet complete. This reduces feed costs, but it often leads to an increase in the overall costs of production by increasing the amount of feed required and the time required to produce a market pig. For example, lysine is the first limiting amino acid in pig diets. Since lysine and other amino acids are used primarily for muscle protein synthesis in growing-finishing pigs, a lysine deficiency would be expected to reduce the rate of growth, increase the amount of feed required per unit of weight gain, and reduce carcass muscling. It is uneconomical to feed below stated lysine requirements. Similarly, because phosphorus is an expensive mineral, adequate amounts may not be included in the diet. A marginal dietary deficiency of phosphorus depresses the growth rate and feed efficiency of pigs. A marginal deficiency of calcium does not influence growth rate or efficiency of gain, but a deficiency of either phosphorus or calcium reduces mineralization of bone, which can cause leg weakness, lameness, and pathologic fractures.

Most of the activity in nutritional research of the growing-finishing pig deals with refinements of specific nutrient requirements and the source, digestibility, and use of specific nutrients.

There is now much interest and research in the nutrition of the finishing pig to achieve the optimum carcass score within the genetic capability of the pig and to produce more lean pigs. As the pig grows, maintenance requirements and fat deposition rates increase, and the efficiency of conversion of feed into liveweight decreases. Pig growth above 90-kg liveweight is characterized by very rapid rates of fat deposition and a marked deterioration in feed efficiency. The relationship between liveweight, feed efficiency, and lean content is largely dependent on the lean-tissue growth potential of the animal. Any increase in the daily rate of gain of lean-tissue growth will cause a reduction in the amount of fat deposited in the carcass, an improvement in feed efficiency, and, therefore, an increase in the slaughter weight at which the unit of costs of production are minimized (Ellis and Horsfield, 1988). Consumer attitude surveys have shown that a low ratio of fat:lean tissue is demanded at the point of sale. However, although the consumer prefers lean pork, overlean carcasses may have unacceptably soft fat tissues. As pigs get leaner, the fat quality declines. The condition of PSE muscle, which causes excessive drip loss at retail sale and weight losses through the marketing chain, is most obviously associated with carcass leanness in certain breeds. The aspect of meat quality most often associated with carcass composition is PSE muscle, and the most important aspect of quality linked to carcass composition is eating quality. Therefore the challenge is to find the balance between the

desirable amount of lean and backfat and the optimum nutrition of the pig that causes the maximum margin of profit. The goal of producing a pig with a predetermined amount of carcass fat is not possible at this time. The processes of fat synthesis and fat mobilization are well defined in the pig at the various stages of its life, as are many of the factors that influence fat metabolism. A variety of feeding systems are available; each has advantages and disadvantages that vary from farm to farm, depending on the level of management, the type of housing, and the feed used.

The quantity and quality of protein should be maintained at full-feed rates if maximum response to limited feeding is to be obtained. Limited feeding can be done by the inclusion of high-fibrous feed ingredients to restrict energy intake or by limiting daily feed intake. The use of high-fibrous diets reduces feed conversion efficiency, which increases the cost of gain. In general, a decrease in dietary energy density leads to increased dry matter intake, but as a result of the lower density, daily intake of net energy is reduced, which influences pig performance and carcass characteristics. Restriction of the daily amount of diet has the potential for improving feed conversion ratios by reducing feed wastage, increasing digestibility of the feed, and lowering the energy required to produce a unit of gain (Kornegay, 1986a). The research on the efficiency of feed utilization in pigs has been reviewed briefly (Bereskin and Steele, 1988). Feed efficiency is one of the most important traits in pork production, because feed represents 60% to 80% of the cost of raising pigs, and breeding stock suppliers should consider the improvement of feed efficiency as a selection objective. Direct selection for feed efficiency has been less successful than expected, but selection for an index that combines growth rate and backfat as an estimate of lean tissue growth rate has been as effective, or more so, than direct selection for feed efficiency. The physiology of the controls of feeding in pigs has been reviewed. The factors that affect appetite of the pig will become more important in determining the efficiency of pig production. The dietary factors involved in feed intake regulation in growing pigs have been reviewed.

Antibiotics have played a major role in the growth and development of the pig industry for more than 30 years. Their efficiency in increasing growth rate, improving feed utilization, and reducing mortality from clinical disease is well documented. Because of consumer concern about drug residues in meat products, and the fact that the continuous use of antimicrobials may contribute to a reservoir of drug-resistant bacteria in animals that could be transferred to man, alternative methods of growth promotion are being examined.

Veterinarians specializing in swine health and production management are providing nutritional consultation to swine producers who mix and formulate their own rations on the farm. Homegrown or purchased grains are mixed with a purchased protein-mineral-vitamin concentrate mix. This requires a regular system of analysis of the feed grains used. A record of the total amount of feed used during the period is vital information for the assessment of feed efficiency from weaning to market.

On-farm feed production generally involves grinding and mixing grain that is produced and stored on the farm with concentrated commercial feed products. The purchase of complete feeds from a commercial feed mill offers the advantages of high quality assurance, convenience, and other services provided by the feed industry. However, the additional cost of this service and the necessary transportation may not be economical, and on-farm feed preparation has become popular as a result of the substantial reduction in feed costs. However, many producers are unaware of the increased management responsibility and the importance of quality control when preparing feed on the farm. Manufacturing feed on the farm requires additional labor, capital investment, and knowledge of nutrition to evaluate and purchase economical feed ingredients so that the diets can be formulated properly to meet the needs of the various classes of pigs in the herd. Quality control of on-farm mixed feeds is extremely important to minimize nutrient variation relative to final target levels. The addition of expensive major nutrients, such as protein and minerals, in excess of those required to meet the pig's nutrient requirement causes an unnecessary increase in the cost of pork production. Conversely, nutrient levels excessively below the pig's requirements increase the cost of pork production as a result of suboptimum pig performance. Surveys have revealed that many pig diets are not formulated or mixed correctly to meet the desired nutrient levels in the complete feed. The economic impact of these manufacturing errors is significant, and it is important to develop an on-farm program to improve quality control of the feed. The considerations for ensuring quality feed manufacturing include the following recommendations:

1. Obtain laboratory analyses for cereals and protein ingredients.
2. Formulate diets correctly. The nutrient levels for each ingredient must be obtained and the recommended nutrient levels for the class of pigs to be fed must be determined. Most nutrient recommendations are based on those published by the NRC with an added safety factor to account for biological variability.
3. Follow directions on commercially prepared ingredients.
4. Minimize errors when adding ingredients to the mixture. All bagged ingredients should be labeled properly and a checklist should be used to record each ingredient added to the mix.
5. Mix ingredients accurately. Accurate scales are needed for this step.
6. Premix ingredients with low inclusion rates. Feed ingredients with low inclusion rates (e.g., 1% to 2% of the total diet) should be premixed with grain or protein supplement before they are added to the complete mix. This facilitates even distribution of these ingredients.
7. Add ingredients to the mixer in the proper sequence. To facilitate satisfactory ingredient distribution in the mix, at least one half of the grain should be added first, followed by all premixed ingredients. Next, all of the protein sources should be added. Finally, the remaining grain should be added to complete the diet formulation specifications.
8. Allow enough time for adequate mixing. Mixing for 10 to 15 min in a vertical mixer and 5 to 8 min in a horizontal mixer provides satisfactory ingredient distribution in the final diet.
9. Avoid filling mixers beyond capacity.
10. Minimize segregation of ingredients.
11. Clean mixing equipment between batches.
12. Check mixing and formulation accuracy. Obtain representative feed samples, submit them to a laboratory for analysis, and compare the results with calculated levels of the diet formula.

Strategic Medication of Feed and Water of Growing and Finishing Pigs

When epidemics of infectious diseases occur during the growing-finishing periods, antimicrobials may be added to the feed and water supplies, initially at therapeutic levels for up to several days, then followed by prophylactic levels for a few weeks. They should be used selectively and strategically to control or eradicate specific infectious diseases. Routine indiscriminate use of antimicrobials should be avoided because of cost, the possible development of drug-resistant pathogens, and the false sense of security that develops in

the herdsperson. Swine dysentery can be eradicated from a herd by the judicious use of mass medication of the feed of the entire herd.

In swine feeder operations that purchase weaned pigs from a variety of sources, each with a different spectrum of diseases, the incidence of infectious disease of the respiratory and intestinal tracts is usually much higher than in self-contained herds, and there is no reliable method for control. The best that can be done is to provide the most comfortable environment that is economically possible, to treat individual sick pigs as they are detected, to submit dead pigs for necropsy, to mass medicate at strategic times if appropriate, and to practice the AIAO method of management.

The diagnosis must be as accurate as possible if mass medication of the feed and water is used as a method of treatment of the herd. Mass medication of the feed and water supplies of feeder pigs is not without problems. In addition to the costs, it is not always possible to medicate feed supplies that are already in place in storage on the farm, and the medication of water supplies is often difficult to do selectively unless there is a double waterline in each pen, one of which can be turned off. Medication of the entire watering system may not be necessary and is expensive. The withdrawal period for each feed additive must be followed to avoid drug residues in meat supplies. Tests to detect drug residues in pigs after slaughter are now available and are used for statistically valid random sampling of pork in abattoirs. The development of on-farm tests to detect residues in live animals before they leave the farm would assist producers in their drug-residue avoidance program.

The AASV has recently issued a statement reiterating its commitment to the use of scientific knowledge and skills for the benefit of society. Culture and sensitivity results should be used to aid in the selection of antimicrobial. Therapeutic use should be confined to appropriate clinical indications. Therapeutic exposure should be limited to treating only for so long as needed for the desired clinical response and should be limited to treating only the ill or at-risk pigs, treating the fewest animals indicated. Judicious use of antimicrobials, when under the direction of a veterinarian, should meet all the requirements of a valid VCPR. Prescriptions, veterinary feed directive, and extra-label use of antimicrobials must meet all the requirements of a valid VCPR. Extra-label therapy must only be used where deemed appropriate and not expressly prohibited (chloramphenicol, clenbuterol, diethylstilbesterol, dimetradazol, ipronidazol, nitroimidazol, furazolidone and nitrofurazone (except for approved topical use), fluoroquinolones, and glycopeptides (e.g., vancomycin). Veterinarians should work with those responsible for the use of antimicrobials to ensure that they are used judiciously. Regimens for therapeutic antimicrobial use should be optimized using current pharmacological information and principles. Antimicrobials considered important in treating refractory infections in human or veterinary medicine should be used only after careful review and reasonable justification. Contamination of the environment with antimicrobials should be minimized whenever possible. Accurate records of treatment and outcome should be used to evaluate the therapeutic regimen.

Vaccination and the Use of Anthelmintics and Insecticides

In herds that encounter epidemics of pneumonia from *M. hyopneumoniae,* vaccination of all pigs in the growing-finishing group may be indicated. Other vaccinations are now very uncommon.

Anthelmintics and insecticides should be used when indicated for the control of intestinal helminthiasis and skin diseases caused by arthropods. However, control of these diseases is accomplished most effectively by regular treatment of the adult stock, which minimizes spread to the weaned and growing pigs. Treatment of sows with an anthelminthic approximately 1 week before entry into the farrowing crate used in conjunction with good sanitation and AIAO production has been shown to adequately control roundworms.

Continuous Surveillance of Animal Health and Production

Pigs in the growing and finishing pens must be inspected visually twice daily for evidence of clinical disease. Dead pigs must be removed from the pen as soon as possible. A daily record of the number of pigs with clinical disease and the treatments given should be kept and reviewed by the veterinarian at each herd health visit. A monthly report should be prepared, and recommendations for specific action should be submitted to the producer. A record of the average days to market and the amount of feed used for a group of pigs or the total number of pigs over the entire feeding period is vital information.

Careful Handling and Transportation at Time of Shipping to Abattoir

Finished pigs identified for shipment to the abattoir must be handled as carefully as possible during sorting and loading to prevent PSS and PSE as well as other injuries. Overcrowding in the transport vehicle must be avoided, and in hot weather, the pigs should be transported during the cooler parts of the day. Prolonged time in the truck leads to higher mortality rates. Training of personnel of correct handling methods is important (Guise et al, 1994).

The handling facilities at the abattoir should be designed to minimize excitement and stress associated with the movement of animals during weighing, crowding, sorting, and killing (Grandin, 1993). Swine-handling facilities must be designed for a pig's shortened range of site and fear of unfamiliar circumstances. Pork quality may be defined as those factors associated with the appearance and palatability of fresh and processed pork. These factors include color, texture, firmness, and marbling of pork muscle. Several slaughter factors affect pork quality and are of concern to the meat packing and processing industry, the meat retailer, and the consumer. A major pork quality problem is PSE, which is associated with those factors that affect muscle pH and with the temperature during the slaughtering and chilling process. Stunning, bleeding, and chilling procedures, which slow down the glycolytic process and production of lactic acid, assist in maintaining normal pork quality.

Residue Avoidance in Pork

Consumers are concerned about the safety of the pork they eat and whether or not it contains chemicals from pesticides or drug residues from the use of drugs in the feed or for the treatment of pigs, and the possibility of the development of drug-resistant bacteria from the use of chemotherapeutics as growth promoters in the feed of swine. Regulatory authorities now regularly advise livestock producers about the incidence of drug residues. Residues of antimicrobials, anthelmintics, insecticides, and other therapeutic and prophylactic chemicals may be present in market pigs (e.g., barrows and gilts) if the producer fails to observe the withdrawal time for the drug

before slaughter or if these compounds have been added to the feed and water supplies unknowingly. The cause of the residue most frequently cited by the field investigators was failure to observe the withholding time for the drug. Other causes include cross-contamination on the farm or in the feed mill. Failure to clean the feeders when switching from medicated to nonmedicated feed and the clinging of sulfamethazine to the metal walls of milling and storage equipment are sources of the drug. Additional sources include accidental access of pigs to a source of medicated feed, recycling of waste water from lagoons, access to accumulated feces and urine in holding facilities, the unapproved use of the drug, extralabel use of drugs by veterinarians, and contamination of the watering system. Legally, the producer is responsible for the presence of residues in pork, and the veterinarian who prescribes drugs to swine for extralabel use becomes legally liable. A Food Animal Residue Avoidance Data Bank is now available to extension specialists, veterinarians, and other needing information on potential residue problems (Sundlof et al, 1986).

Drug-residue avoidance in pork can be achieved by giving special attention to those segments of the industry that lead to the majority of violations (Van Dresser and Wilcke, 1989). Guidelines for the proper use of drugs and growth promoters in feeds for swine are available. Veterinarians must become involved in educating the food-animal industry about drug withholding times. Educational efforts should emphasize the importance of record-keeping, including efforts to identify animals from their source to their entry into the food chain. To improve the knowledge base on drug residues, studies of the appropriateness of stated withdrawal periods should be conducted for a number of drug products used in food animals. This includes pharmacokinetic studies of the residues in pigs after extralabel use of drugs.

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CHAPTER 16

Health and Production Management in Sheep Flocks

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WORLD SHEEP TRADE

The world has a sheep population of about 1.2 billion, occupying largely the difficult environments for agriculture, particularly the mountainous and semiarid areas (Marai and Owen, 1987). Sheep have also been associated with traditional subsistence systems, especially in developing countries, that have remained largely unchanged for centuries. Sheep provide meat, milk, and wool as main products for their keepers. Although there is still a major role for traditional systems as efficient converters of rangeland and by-products, circumstances are changing in many respects. This calls for a reassessment and modification of traditional sheep and sheep-keeping methods. Where good land and various other factors are favorable, sheep genotypes are capable of much higher productivity, although not always at a higher rate of efficiency and profitability.

The distribution of sheep throughout the world is unequal. In some countries the production and export of wool and sheep meat comprised a large part of the gross domestic product when there was a demand for wool, lamb, and mutton. Certain geographic factors and climatic characteristics favor the production of sheep, whereas others exclude the keeping of sheep (Fraser and Stamp, 1987). There are few sheep in either equatorial or subarctic regions, and many sheep on islands and in coastal regions. There is a close association between a 50- to 100-mm annual rainfall and the density of the sheep population.

Historical Considerations

The historical and commercial factors that influenced sheep production and population on a worldwide basis are interesting (Fraser and Stamp, 1987). In Europe, Britain, Spain, and the Balkan countries are the three main areas of sheep production. The countries of the European Economic Community have about 92 million sheep, of which France has about 11 million. Britain has about 37 million sheep and, historically, sheep have been important for Britain because they provided wool for clothing. The export of raw wool from England to Europe was once of primary importance to the country's wealth, preceding the development of a trade in manufactured woolens by some centuries. Lord Ernle wrote, "Wool was the chief source of the wealth of traders and of the revenues of the Crown. It controlled the foreign policy of England, supplied the sinews of our wars, built and adorned our churches and private houses" (Fraser and Stamp, 1987). The Lord Chancellor's sitting on a woolsack is a reminder that the wealth and majesty of England once rested on a solid and elastic foundation of sheep's wool. England then became a wool importer to meet the needs of the wool products manufacturing industry, which soon exceeded the relative importance and resources of the national sheep industry. The Industrial Revolution, the increase in manufacturing industries, and the growth of urban population led to an increase in purchasing power, affluence, and the consumption of meat. Roast beef was the traditional meat dish, but, because of increased demand and the lack of modern refrigeration, sheep became a source of meat. This was followed by the development of the English breeds of mutton sheep, which retain their preeminence throughout the world today. This diversion from the old short- and long-wooled flocks to the English breeds of mutton during the late eighteenth and early nineteenth centuries has helped maintain the viability of the sheep industry in Britain, in spite of the development of wool production in the Southern Hemisphere.

The merino breed of sheep, known for its fine wool, originated in Spain, which maintained a monopoly of production of merino wool for centuries. From the end of the eighteenth century, however, merino sheep spread to England and other European countries but most notably to South America, South Africa, Australia, New Zealand, and the United States. Spain lost its reputation for fine-wooled sheep to Australia.

The sheep in Italy and the Balkan countries are the triple-purpose breeds of sheep that produce wool, milk, and mutton. These are being replaced by specialized, dairy-type breeds; the seasonal migration of livestock and the people tending them, dependent on the use of natural grasslands, are giving way to modified systems of increased density. There are 40 million sheep in former East Germany, Poland, Hungary, Rumania, and Bulgaria. Larger, more specialized flocks are becoming more common in these countries.

In the Southern Hemisphere, there are four great and important areas of sheep concentration: Argentina and Uruguay in South America, South Africa, Australia, and New Zealand. Each of these countries has had much the same economic history related to sheep, beginning with the importation of the wool-producing merino sheep between the mid-eighteenth and mid-nineteenth centuries and the development of an export trade in wool, followed by diversification in the production of mutton and lamb with the introduction of refrigeration. These new centers of sheep production were favored by inexpensive and abundant land and favorable climatic conditions, and now contain about half of the world's population of sheep. The development of the sheep industry in the Southern Hemisphere led to a steady decline of wool production in industrialized European countries. Also, the export of frozen lamb to Britain and other European markets has caused some dramatic changes in the economy of the sheep industry, making it much more difficult to make a profit from sheep farming.

For many years, Australia was the world's largest sheep producing country, with total numbers ranging from 135 to

170 million. It is the largest producer and exporter of fine wools, but because of declining markets the sheep population in Australia has been decreasing, and it is now the second largest after the former Soviet Union, with 140 million. In 1991 the wool market in Australia collapsed, and the government was almost paying farmers to kill sheep in order to decrease the numbers. New Zealand imported its merino sheep from Australia in 1834, and, until the time of refrigeration, its major export was merino wool. In the early part of the twentieth century, New Zealand diversified quickly to lamb production in addition to wool, which has led to excellent fresh and frozen lamb for home consumption and export. In developing the lamb market, New Zealand did not sacrifice its wool market, which has changed from fine merino wool to a fairly coarse and crossbred wool that is used primarily in carpet manufacture.

The United States, India, and the former Soviet Union have sizable sheep populations. The sheep population of the United States decreased from 51 million in 1939 to 33 million in 1960 and to 13 million in 1976, a trend that appears to be permanent. Presently there are about 7 million ewes in the United States. The size of sheep flocks varies from a few kept by hobby farmers to several thousands by farmers who are in commercial sheep farming as a primary source of income. In the United States, in 1982, 50% of sheep farms had 1 to 25 head of sheep and lambs, 33% had 25 to 99, 15% had 100 to 999, 7.5% had 1000 to 2499, and 0.9% had 2500 or more. Small flocks are kept on many farms to use forage on small acreages that cannot be marketed. On western United States ranges, sheep consume forage that would otherwise have no economic value. Large flocks dominate in the western ranges, and, although only about 2% of producers have 1000 head or more, they produce about 70% of the sheep. The early settlers brought sheep with them, but improved breeds were not introduced until the nineteenth century. Merinos were introduced, and the sheep industry developed in the West because of cheap grazing and access to the large, undeveloped lands. American sheep of the western states still contain much merino breeding, even though wool in the American sheep industry has become a by-product of lamb. The merino is suited for the western states because of its close flocking instinct, which makes herding on open ranges much more practicable, and because the merino is the type of sheep suitable to semiarid climates. In the eastern states, sheep play a minor role in the economy of the mixed farm, and English mutton breeds prevail.

India and Pakistan together form a vast subcontinent of agricultural villages that might be expected to have a large concentration of sheep similar to the peasant communities of southeastern Europe. However, the hot and dry climate, although favorable to wool-bearing merinos, is not favorable to mutton and milk production. The former Soviet Union has the largest flock of sheep in the world, some 140 million. Before the Bolshevik Revolution, it supported a large sheep population consisting of triple-purpose, coarse-wooled sheep held by the peasantry and of the fine, merino-type breeds owned by the large landowners. Higher textile standards were achieved by large importations of fine-wooled breeds from Australia, and the adoption of artificial insemination (AI) on a wide scale was designed to accomplish this. Because of the harsh winters, both wool and sheepskins are of particular importance in providing clothing. During the World War II and early postwar years, both the sheep population and wool production suffered a severe recession, from which they have not recovered. Nevertheless, with its large sheep population, the former Soviet Union is second to Australia in the production of wool and is a leading importer of wool. Mutton production is being encouraged.

In North America, sheep are managed under a wide variety of conditions, including extensive range operations, semiconfinement, total confinement, and hobby farm systems. The degree of owner observation, individual animal identification, and systematic record keeping varies considerably in these systems and is sometimes inadequate. A primary task of the veterinarian in sheep practice is to educate producers about health and production aspects of sheep and the value of careful observation, identification, and record keeping for the improvement of flock health and productivity.

In Canada, in 1988, it was estimated that there were 365,000 breeding ewes and 330,000 lambs. Purebred flocks varying in size from 50 to 300 or more ewes, depending on the country, are kept for the production and sale of replacement rams and ewes for both the purebred industry and commercial breeders.

Sheep are kept under extensive and intensive conditions. For example, in Scotland, the stocking rate varies from one ewe to 2 to 3 hectares on uncultivated hill pastures to 12 or 16 ewes to a hectare of cultivated pastures. There has been a trend toward intensification of sheep farming with highly efficient systems dependent on high-quality forages and large inputs of concentrates to achieve production targets of 175% weaning rates with twin lambs reaching 40 kg by 14 weeks old. However, sheep use an extremely wide range of feed resources, and the utilization of vast areas of natural grasslands is one of the merits of the species. Thus grasslands continue to play an important role in sheep systems of all types. The area of grasslands in the United Kingdom, particularly that under 5 years old, continues to decline, whereas there has been a 30% increase in the national sheep flock, which now exceeds 23 million breeding ewes. The overall effect has been increased pressure on the grasslands (Johnson and Evans, 1986) with high stocking densities supported by high inputs of artificial fertilizers, particularly nitrogen, on short-term grass leys.

Lamb feedlots with capacities varying from a few hundred to tens of thousand head purchase lambs and finish them on a high-level grain diet. Approximately 6 million lambs are marketed for slaughter annually in the United States (Salman et al, 1988b).

The world sheep trade consists of wool, mutton, and lamb production. Wool is extremely variable and diverse in type and the wool manufacturing trade is complex because of the blending or mixing of wools during manufacture. A single piece of cloth may contain wool from several continents. Wool may be broadly classified into merino, crossbred, and carpet wool. About 90% of merino wool in the world is produced by Australia (the largest producer), South Africa, Argentina, and the former Soviet Union.

The crossbred wools, which are not necessarily from crossbred sheep, are produced in New Zealand, Argentina, Australia, and the former Soviet Union. The carpet wools are produced mainly in the former Soviet Union, China, India, and the Balkan States. All the industrialized countries of the world are importers of raw wool. Former West Germany is the largest user of wool per person. Most of the wool produced in Australia, New Zealand, and South Africa is sold at public auction by wool brokers who sell on behalf of the producer. The success of the world trade in wool depends on the success of the producer and woolen manufacturer in dealing with the competition of synthetic fibers used in the manufacture of human clothing and carpets. To promote the use of wool and to conduct research and development on the use of wool, the International Wool Secretariat (IWS) based in London, with offices in 30 countries, was established in 1937. The wool mark was introduced by the IWS in

1964 as a symbol of quality, which ensures the buyer that the product is manufactured from virgin wool. A set of quality control systems associated with the wool mark ensures that the product meets certain technical requirements, such as resistance to rubbing and snagging, fabric strength, and colors remaining fast to light and liquid. The wool blend mark introduced in 1971 indicates blended fabrics with a content of more than 55% wool.

The world trade in mutton and lamb is more limited than that of wool. The European Economic Community has only 6% of the world's sheep but produces 11% of the total sheep meat and contributes to one third of world trade. Australia and New Zealand account for 80% of world trade exports, and Britain, France, and Japan represent 40% of all sheep meat imports. At one time, New Zealand depended on the export of frozen lamb to Britain and France for a major portion of its gross national product. The consumption of lamb in Britain has traditionally been high, but consumption has been dropping, which has seriously affected agricultural prosperity of New Zealand. The predominant supplier of mutton is Australia, with Japan as the major importer.

Sheep dairying is a significant activity in the sheep industry (Dawe, 1990). Sheep milk is highly nutritious and is an important component of family sustenance for many millions of people in the favored environments of the world. The sheep dairy industry is concentrated in the more advanced countries of the Mediterranean basin. Sheep dairying is now a growing industry in Australia, Israel, and France. Sheep's milk is rarely used in the liquid form but is generally used for the production of cheese and yogurt. Sheep milk produces double the yield of cheese obtainable from cow or goat milk (Treacher, 1987). Sheep yogurt is finer, smoother, and about 50% more nutritious. Most flocks are hand milked, which is physically demanding and often done outdoors while exposed to the weather. In spite of the availability of effective milking machines, machine milking has not been widely adopted.

The sheep dairying industry has been described (Dawe, 1990; Mills, 1989). Animal health problems, particularly internal parasites, mastitis, and diseases of the feet, seriously limit the productivity of sheep dairy enterprises in Australia. An excellent review of these problems in dairy sheep has been published (Philbey, 1990). The intensive, pasture-based systems of sheep dairying favor the development of gastrointestinal nematodes. Acute mastitis causes death, and subacute mastitis causes loss of milk yield. Lameness caused by footrot is also a major cause of economic loss.

Potential for Sheep Production in Developing Countries

There is a large, untapped potential for improving the productivity of sheep and goats in developing countries (Johnson et al, 1986). This is explained on the basis of the substantial numbers of animals that already exist, the gap between average and best observed productivities, the opportunity to increase emphasis on market-oriented incentives, and the feasibility of realizing major increases with low costs of inputs (Nygaard and Amir, 1988; Johnson and Evans, 1986). In 1980 the lesser-developed countries accounted for 56% of the world's estimated 1.2 billion sheep and 96% of the 460 million goats. The importance of animals to people and the role of small ruminants in farm families in developing countries have been documented. They can obtain their nourishment from grasses and other fibrous forage, which people cannot use directly. In turn, humans are provided with an adequate supply and proper balance of energy, minerals, vitamins, and essential amino acids, which is necessary for human metabolism. Increasing the productivity of sheep and goats represents a hope for improving the living standards of undernourished poor people in the lesser-developed countries (Devendra, 1981). The nonfood contributions of ruminants, many of which cannot be determined precisely, are also substantial. However, at the present time, few research projects focus on livestock issues, and financial support is small. Reports have suggested that sheep play a crucial role in agricultural production, especially in western Asia and North Africa, but there is not much research effort and few new programs that promote production (Thomson et al, 1987).

To realize the potential just described, traditional farmers must place more emphasis on producing for the cash market and thus have more incentive to adopt new technology. Johnson et al (1986) have suggested that ensuring that appropriate new technologies are available for sheep producers in the lesser developed countries requires a six-step research effort: a description of the farming system, applied research on components of the farming system, linkage with international networks for basic research having widespread application, multidisciplinary experiments to examine interactions among system components, and on-farm validation and institutionalization of a dynamic system for technology innovations. This last step is especially important, but often overlooked (Johnson et al, 1986). The institutionalization of a dynamic system for the continued monitoring and improvement of on-farm technology—with effective, permanent lines of communication among farmers, researchers, extensionists, and support personnel such as veterinarians, bankers, and marketing specialists—is the most critical of all if the effort expended on the first five steps is to lead to permanent, ongoing improvements (Johnson et al, 1986).

The Small Ruminant Collaborative Research Support Program was established in the early 1980s to develop research projects oriented toward flock health and veterinary extension activities, and more recently toward infectious diseases, in countries such as Brazil, Kenya, Peru, Morocco, and Indonesia (Alexander et al, 1989). The first decade of animal health investigations in these countries has revealed that infectious and parasitic diseases continue to be a major constraint for small ruminant production. The economic value of small ruminants such as sheep and the low incomes of most owners limit the health care intervention that can be applied. The costs of anthelmintics and vaccines often prohibit owners from using these products to control the major diseases of sheep and goats.

The Small Ruminant Collaborative Research Support Program has also conducted research on the breeding and genetics of sheep and goats in participating countries (Bradford et al, 1989). The results indicate the importance of evaluating local breeds and provide evidence for opportunity for genetic improvement through breeding programs based on local genetic resources, as well as on the judicious introduction of breeds selected for specialized performance.

ECONOMICS OF SHEEP PRODUCTION

The economics of sheep production in the United Kingdom have been described (Nix, 1988) and are updated annually by the Meat and Livestock Committee (MLC, 1997). In terms of gross margin of profit, sheep production has been comparable with other livestock enterprises. Production data for 1996 reveal an average gross margin per hectare for a lowland spring lamb flock of £868 ($1200)/hectare. Since the introduction of sheep quotas based on breeding females, the sheep numbers in the United Kingdom have remained

static over the past 8 to 10 years. Many sheep farmers have a medium to large area of land (approximately 250 hectares) with a low income requirement; therefore a good profit can be generated. Such farmers usually like sheep, too. Two thirds of U.K. farmers own their land and have no mortgage. Sheep also have a low capital requirement compared with most of the alternatives. Little specialized machinery is required, and the feed requirements with March to April lambing follow the natural growth cycle of grass, although with increasing litter size, concentrate supplementation during late gestation is essential. Housing is not necessary except for short periods during lambing time, and usually old buildings, or multipurpose buildings, can be adapted suitably.

The major factors affecting gross margin per hectare are stocking rate, which accounts for 40% of contributions to sheep profitability, and lambing percentage, which accounts for 20%, although these data are generated from a relatively small population. Many low-ground sheep flocks in the United Kingdom wean in excess of 160 lambs/100 ewes mated. When such increased production figures are considered, the lambing percentage assumes a much greater role in affecting gross margin. A high lambing percentage necessitates high labor costs over 1 month (with extra care being given to every ewe at lambing and to every lamb after birth), increased concentrate feeding, and good quality forage. Thus it is essential to ensure high lamb survival rates and rapid growth rates such that these additional variable costs do not exceed the extra revenue obtained (Nix, 1988).

In northern Europe, especially Britain, wool is a by-product of intensive lamb production for meat. High meat prices and subsidies mean that wool accounts for less than 10% of income from sheep flocks (Ryder, 1987). Financial results produced for 1996 revealed that wool now accounts for less than 5% of the gross margin per ewe (MLC, 1997) and continues to decline still further. In southern Europe and parts of the Middle East, milk is the primary product of the ewe; this pushes wool (usually of the carpet type) into third place so that it often produces not more than 5% of income.

In North America the sheep industry consists primarily of large range flocks in the Western states managed extensively with minimal inputs, lambing once annually, and the production of pasture-fed lambs, which either are marketed or go into feedlots for short-term feeding. Wool is a by-product of these flocks. There are also some smaller, more intensively managed flocks in the Midwestern and Eastern states, which lamb more than once annually and produce heavy lambs, with wool as a by-product.

Sheep Industry Characteristics Affecting Animal Health and Production Management Services Veterinarians Provide

In many countries the sheep industry is similar to the beef industry in that many producers operate on a low-input, low-realization basis. Their enterprises are a way of life that has changed little in several generations, and they tend to resist change. Because the individual commercial sheep is of relatively low economic value compared with other food-producing animals, sheep producers have not asked for veterinary assistance to the same extent as cattle producers in the past. In New Zealand, with its large sheep population, the average number of veterinary hours per veterinarian spent annually in sheep practice is small; is less than the number of hours devoted to small animals, dairy cattle, and horses; and is about the same as that spent in beef cattle and goat practice (Boland and Morris, 1989). In contrast, in many European countries numerous flock advisory schemes have been operated by private practitioners. For many farmers sheep are the sole source of income, and veterinarians have endeavored to develop a working relationship with sheep producers, who traditionally perceive that veterinarians did not know much about sheep production (Wise, 1987).

Many large animal (rural) practices have provided the necessary veterinary services and animal health supplies such as anthelmintics and vaccines that sheep producers requested. These large animal practitioners have provided a major service by selling animal health supplies (dips, vaccines, anthelmintics) and by spending a large amount of time in giving advice on the use of these products in an animal health management and production program. In addition, veterinarians in diagnostic and research laboratories and industry veterinarians have made major contributions to the sheep industry.

Technology Transfer

Sheep producers have been traditionally slow to change their practices and techniques of management. However, since the 1980s, there has been an influx of new, younger, and more educated, innovative, and knowledgeable producers who recognize the importance of targets of health and production performance and who want to optimize production and maximize net income.

In sheep farming on extensive range, the risks of poor productivity or heavy losses are so large because of natural influences such as drought, flood, and poor feed supply, so high profitability is variable. The price of wool has also been extremely volatile until fairly recently, and this did not encourage financial investment in the wool enterprise. Sheep farms with intensive management on fertile ground in high-rainfall or irrigated areas have been more receptive to a high-input veterinary service. The availability of free government services in some countries has also restricted the development of private practitioner services.

Potential Market for Sheep Veterinary Practice

In some countries, there is a common assumption of responsibility for veterinary services to sheep flocks by government agencies, especially when strong government veterinary services are available. There are two consequences. Because no fee is involved, there may have been little incentive to carry out a study of the cost effectiveness of the animal health and production techniques that were being used. The lack of participation by practicing veterinarians in the sheep industry has led to much greater involvement of agriculturally trained animal husbandry advisors than in the cattle industries. This trend has been encouraged by the greater importance of production management compared with that of disease control in sheep than in the dairy cattle industries.

Some private practitioners are now providing consulting veterinary services to sheep farmers and incorporating the specialist consultants available from government agencies and universities, such as parasitologists, pathologists, epidemiologists, geneticists, economists, and agrologists (Bell, 1988; Watt, 1983a; Galloway and Grant, 1984). The cooperation among the veterinary practitioner and the government and university specialists provides opportunities for field research and development projects and meets the educational needs of the university to expose undergraduate and postgraduate students to production-oriented veterinary practice. Universities and government agencies provide encouragement, advice, and assistance to established veterinarians, who provide flock health management and production serv-

ices. The provision of flock health and production management services is a complex activity that requires decision making on the farm, often using many and different variables, which in turn requires that current knowledge and new information be sound and evaluated for applicability on individual farms. Thus the veterinarian and advisors must work together and assist the farmer with plans for the implementation of the health management and production methods to be used on the farm. Various sheep health schemes operate in the United Kingdom that involve the private veterinary practitioner in flock health management (Linklater, 1989).

The market for sheep veterinary practice in the United States is only about 4% of the total food-producing animal veterinary medical services (Wise, 1987). Sheep producers spend the least on animal health products and services. As a proportion of the total food animal veterinary service market, sheep practice represents the lowest proportion (about 4%) compared with beef practice (34%), dairy (47%), and swine (15%). Sheep practitioners have suggested that most of their revenue from sheep flocks comes from sick animal services, with a relatively high proportion of that revenue from laboratory and diagnostic services.

Although the total amount has been small, there has been some emphasis on disease prevention and control. This has occurred because of the nature of the veterinary services supplied to the sheep industry. Because of the low individual value of animals and the difficulty of making a clinical examination and diagnosis in a live sheep, the principal preoccupation has been with lethal diseases. The method developed to deal with this was to deliver several dead or badly affected sheep to a diagnostic laboratory. After a diagnosis was made, recommendations for clinical management of the problem were provided, but farm visits to evaluate the problem were not usually made. In the absence of repeated visits to farms to treat sick animals or to participate in disease eradication programs such as the brucellosis and tuberculosis eradication programs, which provided opportunities to get on cattle farms, the development of flock health programs has had no starting point.

The primary objective must be to devise ways of getting onto sheep farms regularly so that the veterinarian can develop familiarity with, and gain the confidence of, the sheep farmer. In New Zealand the major entry onto sheep farms has been through breeding soundness examinations of rams and *Brucella ovis* control. In Australia footrot eradication is providing a similar entry point. In both countries and in South Africa, testing for anthelmintic resistance is a regular and increasing activity, which is a routine annual procedure involving at least one visit. It is also noteworthy that, in New Zealand and Australia, veterinarians investigate flock problems on the farm and submit samples to the diagnostic laboratory as required. Thus considerable progress has been made in the provision of animal health veterinary services on the farm. In the United Kingdom, flock advisory visits during late gestation to monitor late gestation ewe nutrition has proved successful (Scott, 1989).

Having once provided some service to the producer and established a client-veterinarian relationship, it is still necessary to obtain full farmer cooperation. However, compared with the situation in dairy herds, there is great difficulty in ensuring that the regular submission of data by farmers is maintained. This is largely because of the infrequency of visits to the farms required in most programs. If these can be increased without jeopardizing the cost effectiveness of the program, the problem could be resolved. Failing this, the maintenance of telephone and mail contact and client meetings, with reminders of seasonal activities that should be carried out, help maintain enthusiasm.

Sheep Welfare

Aspects of intensive stock farming have become the focus for many animal welfare charities and organizations throughout the world. Sadly, public action has often achieved results in areas in which veterinary submissions to government agencies over many years have failed. Notable examples include public protests at ports that stopped the export of live calves and sheep from the United Kingdom to continental Europe. The banning of sow confinement systems during late gestation within countries of the European Community was the result of public opinion and protest. Public frustration, and that of many veterinarians, has been fueled by the lack of progress in many areas of concern and can be appreciated when reading much of the opinion emanating from various governing bodies. A recent Comment in the Veterinary Record (Anon, 1999) reports thus: "Anyone involved in attempting to achieve improvements in farm animal welfare at the practical level will be aware that progress is often slow and difficult to achieve. They will also be aware that the issues are complex and that well meaning but ill-thought out measures can all too easily have an effect opposite to the one intended."

The importance of animal welfare in sheep production systems was highlighted in the preface to the last edition of this book but has received relatively little attention (Scott et al, 1995a). Although attention to individual sheep cannot be provided in many remote rural areas throughout the world, the high economic value of many breeding ewes in European countries justifies veterinary attention for many procedures. Obstetrical problems are common and provide the veterinarian with opportunities to visit the farm and discuss aspects of production and flock health care in addition to the attention of individual sheep.

One area that has witnessed major advances in the welfare of individual sheep has been veterinary attention of ovine obstetrical problems, including vaginal and uterine prolapses (Scott et al, 1995a,b; Gessert and Scott, 1996) and dystocia cases (Scott and Gessert, 1996a; Scott and Gessert, 1997a,b). Extradural injection of 0.5 mg/kg B.W. of 2% lignocaine combined with 0.07 mg/kg xylazine injected at the sacrococcygeal site provides almost immediate caudal analgesia that lasts for up to 36 hours. This technique greatly facilitates correction of dystocia cases and replacement of vaginal and rectal prolapses. The provision of appropriate analgesia prevents tenesmus, thereby reducing the likelihood of recurrence of the prolapse and greatly improving prognosis. This technique is readily applicable in field situations; it indicates to the farmer and farm staff that there have been important advances in veterinary medicine and provides the opportunity to investigate other aspects of flock management during the farm visit. All too frequently dialogue between veterinary surgeons and their sheep clients has been limited to telephone advice on the use of a particular product; the client having made the diagnosis himself. An outline management system for the welfare of hill sheep in the Scottish highlands has recently been described (MacNab, 1997) and forms a useful blueprint for veterinarians. The visit to the farm to attend an obstetrical case affords the veterinarian the opportunity to look around and, where appropriate, offer advice, make suggestions, and ask questions. Such opportunities to extend and develop sheep flock health programs must be grasped firmly.

Education of the Species Specialist Veterinarian

In many veterinary colleges there is little instruction on sheep, especially in relation to flock health and production management. At the present time, if the veterinarian is to provide highly qualified advice on all aspects of sheep

health and production, the additional education and development of necessary skills may have to come from a combination of several years in practice and formal postgraduate courses that emphasize sheep production. These are available in some veterinary schools, such as the University of Melbourne's McKinnon project (Bell, 1988). In many countries specialized sheep veterinary organizations hold regular national and regional meetings and continuing education courses, which provide an excellent forum for exchange of practical information. In the United Kingdom the Sheep Veterinary Society boasts over 1000 active members. In the United States the Small Ruminant Organization organizes annual conferences and regional meetings.

It is possible for veterinary schools to provide a core elective program in which interested students could concentrate their studies in sheep health and production management during their clinical instruction years. This has not been possible in most schools because they have not had teaching practices large enough, with enough sheep work, to provide the opportunity for students to see a sheep specialty practice. The PEW National Veterinary Education Program in the United States has recommended that food-producing animal teaching centers be established in areas with a concentration of a certain species. Interested students could attend for an extended period of time during their undergraduate years to experience a species specialty practice. This would get around the necessity of every school attempting to provide clinical instruction in every domestic animal species. The development of a sheep farm advisory practice has been described (Bell, 1988).

Becoming a sheep specialist requires continual contact with good sheep farmers and astute observations of their sheep and management techniques, which provides a basis for self-directed learning. A major emphasis is on increasing and maintaining profitability of the sheep enterprises served by the veterinarian. A personal library of books, journals, and proceedings of seminars is a requirement that must be developed along with an effective information-management system that can find and retrieve information quickly. The availability of the Internet affords access to a vast amount of scientific information and allows active participation in specialist discussion groups, even for those veterinarians in remote areas. Communication with experts worldwide on a vast array of subjects allows the veterinarian to keep informed of the latest developments in sheep health and production. The veterinarian must be fully committed to advisory work, which cannot be combined with conventional emergency veterinary practice that provides service for dogs, cats, horses, cattle, and sheep at the same time. Certainly, a veterinarian can combine emergency service with health management service in one or two species, such as sheep and beef cattle, but this requires organization of the veterinarian's time to maximize efficiency.

The practitioner needs a certain amount of clinical experience before moving in the direction of sheep specialty practice. A considerable amount of out-of-hours work is necessary to retrieve the information required to solve flock problems and to provide advice to the producer. The veterinarian usually begins learning on the job by working with a group of sheep farmers who are interested in flock health management. It is with these initial clients that the veterinarian must endeavor to provide a successful service that in turn can produce a good reputation among sheep producers. Reports of flock health visits, along with recommendations for changes in health and production management, are a necessary part of developing an advisory service. Becoming computer-literate for the purpose of producing health and production reports and newsletters is a prerequisite. Additional subjects to be included in such a course are the following:

- Good understanding of sheep production, including the economics of sheep production and the use of partial budgeting
- Genetic management, including objective measurement methods and the handling of large numbers of sheep in a series of levels of differing excellence
- Grazing management: the economy of subdivision, selection of a level of grazing pressure, and selection of pasture species
- Nutrition: body condition scoring (BCS) and adjustment of rations accordingly, with feeding during periods of drought, ewe maintenance, and weaner management
- Reproduction management: times of breeding, duration of breeding period, concentration of lambing, and examination and selection of rams
- Management of lambing to ensure a high level of lamb survival
- Cost-effective control of serious diseases in the particular area
- Familiarity with the physical techniques of shearing, foot care, AI, ovum transplantation, culling of ewes, lamb and sheep necropsies, drenching, fleece appraisal, plunge and shower dipping, and many others

A sheep veterinary specialist certificate and diploma program is now available in the United Kingdom under the auspices of the Sheep Veterinary Society, a division of the British Veterinary Association.

Causes of Economic Losses in Sheep Flocks

There is little published literature on the causes of economic losses associated with disease or impaired productivity in sheep flocks. There have been surveys based on abattoir surveillance (Cuthbertson, 1983), but they have little validity except as indicators of change in prevalence from year to year or season to season. They reflect prevalence mostly in market sheep and are biased toward the young part of the population. Similarly, surveys carried out on material passing through diagnostic laboratories are biased toward fatal diseases and provide no indication of the real waste caused by nonfatal diseases such as footrot, many helminthiases, and nutritional deficiencies. They often do not provide the most basic of all epidemiological data, the size of the population at risk, and the number affected. Such surveys are common for particular sectors of the sheep population, especially lambs (see the "Perinatal Lamb Mortality" section). A survey of diseases diagnosed in adult and feeder sheep submitted to a diagnostic laboratory in Canada revealed that diseases of the respiratory and digestive tracts were most common (Moteane et al, 1979). Based on serological results, subclinical maedi-visna virus infection in sheep flocks can have a detrimental effect on productivity, such as conception rates and birth weights of lambs born to ewes infected with the virus (Dohoo et al, 1987).

A mail survey of diseases in 116 sheep flocks in Canada on the record of performance (ROP) over 1 year revealed a lambing percentage of 153% (1.53 lambs born alive/ewe lambing). This was below the rate observed in all flocks on the ROP program and substantially lower than the 179% lambing rate that can be achieved in some commercial flocks on an estrus synchronization program (Dohoo et al, 1985; Rawlings et al, 1983). Total lamb losses were estimated to be about 12%, but this was probably a conservative estimate. The major identified causes of lamb mortality were starvation, pneumonia, diarrhea, and accidents. Abortions occurred in about half of the flocks, but usually at a

BOX 16-1

Major Causes of Economic Loss

1. Reproductive inefficiency, including failure to conceive and failure to lamb normally with more than one lamb and with an optimum litter size for the environment and level of management.
2. Lamb mortality from birth to weaning. Most of this occurs in the first 2 days after birth.
3. Nutritional inadequacy of ewes during the various stages of the reproductive and wool-producing cycles. The most critical periods are the last 6 weeks of gestation and the first 3 weeks of lactation.
4. Diseases such as internal and external parasites, pregnancy toxemia, blowfly strike (in some countries), suboptimum growth rate in weaned lambs (weaner ill thrift), footrot, mastitis, prolapsed vagina, clostridial infections, and certain specific diseases, such as maedi-visna.
5. Insufficient long-term attention to the breeding program necessary to improve performance.

BOX 16-2

Veterinarian's Role in Flock Health and Production Management Service

Improvement of reproductive performance
Reduction of perinatal lamb mortality
Identification of suboptimum production or sources of loss
Formulation of cost-effective measures to achieve optimum productivity
Maintenance of optimum nutritional status of the flock
Ensuring that the parasite control program is correct (regular fecal egg counts) and monitoring that the chemicals used are effective
Control and possible eradication of specific diseases, such as footrot and *Brucella ovis* infection
Investigations of epidemics of disease
Transfer of new knowledge and technologies, which can improve the efficiency of production

low level, and abortion storms were uncommon. Pneumonia was the most common cause of mortality in ewes, and mastitis occurred frequently; this was often cited as a reason for culling (Dohoo et al, 1985). Prolapse of the vagina or uterus was also a common cause of mortality and a significant cause of culling. In the same survey, the average adjusted weight at 100 days of age was higher than in other types of flocks and the prevalence of diarrhea was lower (Dore et al, 1987). At the herd level, the incidence rates of pregnancy toxemia and vaginal prolapse were associated with heavier lambs, whereas the average daily weight gain between 50 and 100 days of age was lower in flocks affected with diarrhea and starvation. Lamb losses in Australia have ranged from 15% to 20% (Alexander, 1984) and 17% to 35% (Haughey, 1985), and an intensive study of losses in a large Scottish flock reported a total loss of 25.8%, of which 7.2% were stillbirths (Wiener et al, 1983). Further studies in the United Kingdom have reported perinatal mortality rates in excess of 15% (Barlow et al, 1987). In the United States perinatal losses ranged from 10% to 35% of the annual lamb crop (Rook et al, 1990).

Disease wastage in weaners and adult sheep varies from place to place, depending on climate and husbandry practices. An Australian report (Watt et al, 1981) estimated that 75% of ewes, 50% of weaners, and 85% of wether flocks were drenched for worms wastefully, insufficiently, or at the wrong time of the year. There was also a significant neglect of preventive procedures against blowfly strike and clostridial diseases, with more than 50% of susceptible sheep populations left unprotected. Wastage was also predicted in flocks in which a supplementary diet was fed to ewes to avoid pregnancy toxemia, because only 6.8% of ewes bore twins. The degree of susceptibility seemed to be much too low to warrant an across-the-flock feeding program. A New Zealand survey (Davis, 1979) reported a 5% annual rate of death in 24,000 sheep. The most common diseases were pregnancy toxemia, pneumonia, dystocia, blood poisoning, chronic facial eczema, and salmonellosis. In a similar survey covering 3000 adult sheep in Norway, the average loss was 2.7% annually, with most deaths occurring at pasture (Lutnaes, 1982). The most common causes were diseases of the nervous system, mastitis, trauma, metritis, and abortion. Data from MLC recorded flocks in the United Kingdom reveal annual ewe mortality rates from 4% for hill flocks and 5% for lowground flocks (MLC Yearbook, 1997).

In summary, there is general agreement that the major causes of economic loss are those listed in Box 16-1.

Opportunities for Improved Profitability

Because of the wide margins between the levels of sheep production that are economically possible and current levels, there are opportunities for improving the efficiency of production (Owen, 1987b). The best opportunities for the veterinarian to provide a flock health and production management service that can improve profitability in the sheep flock include those listed in Box 16-2.

NEED FOR HEALTH AND PRODUCTION MANAGEMENT

Traditionally, the sheep industry has not consulted veterinarians about flock health and production management. Producers themselves usually have undertaken most of the routine procedures and clinical work required, such as tail docking, castration, vaccination, drenching, obstetric assistance, and treatment of common diseases (e.g., pneumonia and diarrhea) because of the low economic value of individual sheep and a feeling of independence. Veterinarians were called to diagnose and treat sheep affected with diseases and problems that the producer could not or did not know how to manage. Thus veterinarians were consulted only occasionally, and a working relationship with the sheep producer did not develop. In some countries, government-financed agricultural advisors and veterinary sheep specialists began to provide advice on flock health and management, and these services developed into large advisory services that were supplied free to the farmer. The veterinary profession has not developed an expertise in flock health and production management that could be applied to sheep flocks in the business of sheep production because large animal practitioners have been busy with other relatively prosperous

aspects of large animal practice, such as dairy and beef cattle, swine, and companion animals. Consequently, the sheep industry has had the perception that veterinarians are not educated and trained to be useful sheep veterinary consultants.

A variety of new production methods in the sheep industry have provided efficient, profit-making opportunities in sheep production. In some areas, sheep production is becoming intensified successfully because of improved understanding of ruminant nutrition, improved grazing management, improved breeding methods, improved methods of monitoring performance, and providing of advice, better marketing, and effective parasite control (Pollott and Kilkenny, 1987). There is a need for wider dissemination of improved techniques that have been developed and already applied successfully on farms. Techniques are now available for the veterinarian interested in sheep production-oriented medicine to provide a completely integrated, planned health and production management service to sheep producers interested of making a living in sheep production.

A number of flock health programs have been described (Boundy, 1981; Quinlivan, 1981; Hindson, 1982). Flock health and production programs are aimed at applying the techniques of preventive medicine and animal production to commercial sheep enterprises (Galloway and Grant, 1984). They are designed to increase the productivity and profitability of the flock in the context of the objectives of the owners and to increase the welfare of the flock and individual sheep. Historically, the programs for sheep were based on the principles applied in dairy health management, but they emphasized both animal health and production management in the context of a whole-farm approach in assisting the farmer. Comprehensive descriptions of flock health and production programs developed in Australia have been published (Bell, 1983; Watt, 1983a).

The health and animal production components are closely related because adequate health is essential for animal production to be maximized, and because health depends to a large extent on nutrition, genotype, and animal management (Watt, 1983a). The health component in these programs is based on the control and prevention of disease through the application of appropriate measures at strategic times. The appropriate time depends on the epidemiology of the disease on a particular farm. For example, the strategic use of anthelmintics requires a clear understanding of the epidemiology of the parasites in question and an appreciation of what part of the life cycle is most vulnerable to the anthelmintic (Craig, 1998).

The animal production component is based on the information and techniques of the animal sciences, with particular emphasis on animal production from pasture. It attempts to use knowledge of nutrition, reproduction, genetics, and physiology to develop and improve the efficiency of animal production systems to which appropriate preventive medicine techniques can be applied (Watt, 1983a).

Sheep flock health and production management is concerned with the concepts and techniques of disciplines such as economics, agronomy, farm management, and sociology, because the measures recommended and used must be feasible, profitable, and in accord with the objectives of the farmer. The veterinarian acts as a consultant to the sheep farmer by attempting to identify suboptimum production or sources of economic loss, diagnose the causes, and formulate cost-effective measures to eliminate or reduce the losses or to achieve optimum productivity (Galloway and Grant, 1984). The veterinarian then discusses with management which aspects of the program are to be adopted, setting priorities according to cost-benefit ratios, but heavily influenced by the welfare considerations of the sheep and personal goals of the producer. The veterinarian provides advice about the application of new or different health and production methods, attempts to evaluate them in relation to the objectives of the farmer, and then reallocates resources according to current achievements (Blackburn and Cartwright, 1987). Monitoring and advising are conducted in a number of well-defined areas, including reproductive efficiency, internal and external parasite control, vaccination schedules for the control of infectious diseases, nutritional and metabolic disease control, genetic improvement, pasture use, and overall productivity. Contact with the farmer is essential and is maintained through telephone calls, newsletters, discussion groups, and farm visits to carry out the physical work necessary to obtain health and production information and to discuss past performance and future management. Reports are sent to the farmer after each visit, and annual reports are prepared. Recent recommendations made to U.K. government by the Farm Animal Welfare Council strongly advocate that every sheep farm must have a written flock health plan detailing strategic events, vaccination regimens, and treatment procedures. These flock plans will be devised and developed by the farmer's veterinarian who has expert knowledge of that particular farm. Such flock plans afford a great opportunity not only to increase flock health and productivity but also sheep welfare by ensuring that all situations are dealt with promptly and that, more importantly, prophylactic measures are adopted where appropriate.

Types of Flock Health Programs

West (1989) has defined a flock health program as a planned approach to a health or production problem and has described three levels of programs, as follows.

Type I: Simple Control Program

Simple control programs have been offered by veterinarians over many years. They are aimed at controlling or eradicating specific diseases such as *B. ovis* infection, footrot, or helminthiasis, or at the examination of rams for breeding soundness or pregnancy diagnosis of the ewes. In most cases, the veterinary work is task oriented, and some technical skill is required for success of the program. It is relatively easy to receive payment for the work done because the veterinarian is seen to have done something physical, such as examining the rams. There is a minimal requirement for records or writing reports, and in most cases the activity is initiated by the producer rather than the veterinarian.

Type II: Identification and Correction of Production-Limiting Disease Syndromes

Suboptimum reproductive performance, a high mortality rate in lambs, unthriftiness in lambs, ewe mortality, and intestinal parasitism are examples of production-limiting syndromes that must be investigated over time by using a systematic plan. They cannot be solved in one farm visit. These problems and their solutions must be considered part of the total enterprise and the contribution they make to overall farm productivity. The producer may bring these problems to the attention of the veterinarian during a routine visit while examining the rams for breeding soundness, or the veterinarian may recognize the problem while investigating another problem. Investigations of these production-limiting syndromes require sufficient time and in-depth knowl-

edge of sheep medicine and production to prepare reports and persuade the producer that future veterinary visits are required to follow the health and production indexes and to assess the action undertaken. Remuneration for this type of veterinary practice is not obtained as easily, because producers have been reluctant to pay for advice that is a larger part of this type of work compared with type I.

Type III: Whole-Farm Health Management Programs

A combination of types I and II leads to the whole-farm health management program. In this advanced stage the veterinarian acts as a consultant to the producer using the skills and knowledge of economics, partial farm budgets, sheep production and management, applied epidemiology, genetics, and nutrition. Computer programs, such as SheepMan, are now available to evaluate health and production data and to relate these figures to the financial aspects of the flock and farm. Progress is measured by economic improvement on the farm as a whole. In New Zealand, veterinary involvement on sheep farms is concentrated mainly on types I and II flock health programs, with only between 3% and 6% of time devoted to type III activity (West, 1989).

The most common task-oriented activities are ram breeding soundness and brucellosis control, which account for about 53% of all time involved with sheep and represent about 68% of income. Approximately 21% of veterinary time was devoted to troubleshooting that involved specific disease or problem investigation, defined as a type II activity. Advice given over the telephone accounted for 16% of time involved, but only represented about 0.7% to 2.5% of income. However, telephone consultation is often associated with the sale of animal health products, which accounts for a substantial part of the rural veterinary income in New Zealand.

Most veterinarians serving the sheep industry in New Zealand are involved in animal health and production management with an emphasis on types I and II programs. To be effective as a sheep consultant, veterinarians first must have expertise in types I and II programs and whole-farm flock health programs must be viewed as an extension of types I and II activities and not promoted in isolation. The examination of rams for breeding soundness and brucellosis control programs in New Zealand and footrot control in Australia have been the bases from which animal health programs have been initiated.

In Australia, there has been a significant increase in the involvement of veterinarians in the sheep industry (Plant, 1989). A broad cross section of veterinarians—including those from private practice, government advisory services, regulatory services, diagnostic laboratories, and research and development organizations such as universities, government, and commercial industries—are involved. A small but growing number of veterinarians are involved in whole-farm sheep veterinary advice, which includes providing advice on pasture production, stocking rates, time of lambing, flock structure, flock nutrition, shearing management and wool clip preparation, control of external and internal parasites, and breeding stock selection and management.

Beginning a Flock Health and Production Management Program

The increased intensification of sheep farming, coupled with increased capitalization of farms and greatly increased value of individual sheep, has created a need for a cost-effective flock health and production veterinary service. In most sheep-raising areas, preliminary surveys have revealed incomplete adoption of proven, cost-effective health and production techniques (Jelbart et al, 1984). A survey of Victorian sheep farmers indicated that a delay exists between publication of research findings and their communication to the farmer for consideration (Campbell et al, 1984).

In countries where departments of agriculture have traditionally provided on-farm veterinary advice to livestock owners, the initial problem that must be addressed when a flock health program is to be instituted is who should provide it. The situation in most countries has been a tendency to withdraw from free government services to private industry, and the trend is now veering sharply to private practitioners. This means that the costs of the programs are borne directly by farmers, and, if they and their advisors are to have mutual respect for each other's problems, the program must be cost effective and include a means of demonstrating its own economic efficiency.

When it actually comes down to starting a program and telling a sheep farmer that the program is available, there are difficulties compared with the situation in a dairy or beef herd, in which the veterinarian is likely to have been a frequent visitor. The veterinarian must use some persuasive initiative to be invited to the sheep farm to investigate a particular problem and to examine the overall health and production status of the flock. This helps develop a working relationship between the farmer and the veterinarian.

If a sheep farmer indicates an interest in a flock health and production veterinary service, the following steps are recommended for initiation of the program.

Create a Farm Profile

The veterinarian should visit the farm and collect the necessary information to generate a farm profile. This includes a full description of the farm; the numbers, types, and ages of animals; the management system used; the purpose of the flock, including the objectives of the farmer; the breeding programs used, health and production performance indexes within the last few years (lambing percentages, lamb mortality); disease prevention programs, including the use of anthelmintics and vaccines; the costs of veterinary services and animal health products within the past few years; and the costs of production, if available. All of this information is necessary for the establishment of a baseline in the flock and for the identification of obvious problems that are major causes of economic loss, which may be corrected easily.

Identify Immediate Concerns of Farmer

From the initial farm visit the veterinarian may identify certain health and production concerns that the farmer would like solved, and these should be examined as soon as possible followed by corrective action. This may include advice on the use of anthelmintics and vaccines and other routine procedures.

Formulation of Proposal

The veterinarian can prepare a proposal for consideration based on the farm profile. The proposal would include an analysis of the health and production of the flock and the areas of health and production that should be improved first. The veterinarian may wish to incorporate the observations and advice of other consultants; to do this, there must be full cooperation and communication so that the owner receives the same message from each consultant or, if different, a suitable explanation.

Application of the Program

If the farmer agrees to begin the program, the veterinarian may make several visits to the flock to examine the rams, to assess neonatal lamb losses, to do pregnancy diagnosis, to score the body condition of ewes, to examine the flock before breeding or after lambing, to make observations of the flock and management, and to establish a useful record-keeping system. The veterinarian can usually identify those areas of the flock that are most in need of attention and are most susceptible to immediate and economic correction. Most producers are interested in new advice dealing with parasite control, vaccination schedules, and the status of their rams, and in any methods that can increase the reproductive performance of their flocks. However, most farmers, at least initially, are not interested in modifying stocking rate or genetic improvement or in changing the time of lambing. Such changes involve relatively long-term modifications of management and may be risky.

Collaboration with Other Specialists

The veterinarian needs to consult with other specialists such as agronomists and parasitologists as the program is being developed. It is no longer possible for even a veterinary species specialist to be knowledgeable and skillful in every discipline of animal health and production, including the industry aspects of a particular species or class of animal.

Preparation of Reports

The collection of health and production data and the preparation and submission of reports to the farmer within a few days of each farm visit are vital to the success of the program. Farmers are interested in the veterinarian's observations and analysis of flock health and production, and they appreciate written reports. The time of the next visit should be discussed and confirmed with the producer before the veterinarian leaves the farm.

Communication

Once the veterinarian has begun to provide the service, regular communication by telephone, computer modem, fax machine, websites, newsletters, and personal visits is essential to the success of the program. Because veterinarians do not visit sheep farms on a regular basis, as in cattle practice, it is necessary to communicate with the sheep producer in other ways. Regular newsletters outlining new developments in health and production management are effective to keep producers informed. Communication and interaction by the Internet provides exciting opportunities for members of a particular flock health scheme.

Evaluation of the Service

The veterinarian must indicate a willingness to evaluate the cost effectiveness of the program as it is being developed. Farmers are interested in their costs of production and whether new health and production management techniques are cost effective.

FLOCK HEALTH AND PRODUCTION MANAGEMENT

Objectives

The principal goal of a sheep flock health and production management service is to provide individual sheep farmers with the advice and accompanying services that can best enable them to achieve their objectives. For the purposes of this discussion, it is assumed that economic efficiency is the farmer's sole objective. There are many other possible objectives, including economic efficiency to reduce income tax indebtedness and increase capital gain, but they do not appear to require veterinary advice.

It is necessary to point out a common error: the assumption that maximum physical production of wool or lamb is the final goal. This is often not the case, and data on production per hectare should be accompanied by an estimate of cost per unit of product produced.

Although a decision on the cost effectiveness of a simple technique is easy to make, a major difficulty arises when other implications of the technique must be considered. For example, a decision to start supplementary feeding of late pregnant ewes may have a significant effect on the birth weight of lambs and the milk supply of ewes. Lamb survival is likely to be improved as a result. Conversely, the expenditure may compete with another financial outlay such as a prelambing drench. Accordingly, a whole-farm approach is needed for every decision made about health maintenance and, because health and production are inextricably related to each other, to virtually all the decisions made on the farm.

Targets of Performance in Sheep Flocks

In addition to economic profitability, the performance of a sheep flock can be evaluated by comparing actual performance with targets of performance. Sheep producers are interested in achieving certain targets of health and production performance that are profitable and in identifying the causes of failure to reach those targets. A target of performance is one that can be achieved by using current management and production technology. The targets that can be achieved economically vary from flock to flock depending on the nature of the enterprise, the level of management provided, and the geographic area. Targets are determined by the collection of performance indexes in a representative cross section of flocks in the area. A range and an average for each index provide guidelines as to what is possible in similar flocks with similar objectives, feed supplies, environmental conditions, and management expertise. Such data are produced by the MLC in the United Kingdom featuring bottom, average, and top thirds for hill, upland, and lowground flocks. Typically, extensively managed flocks with minimal inputs do not have high performance indexes. Intensively managed flocks that are housed and lamb on an accelerated program or out of season have higher input costs and therefore must be more efficient and achieve higher targets of performance.

The targets in Box 16-3 are suggested as guidelines.

Which of the commonly used indexes is relevant varies with the particular circumstances. In extensively run flocks under ranch conditions, it is usually the survival rate—that is, the longevity—of the sheep that determines whether the enterprise is successful. In intensively managed flocks, survival is a prerequisite and the final decision depends on the rate of gain in body weight of growing sheep or the weight of wool (related to micron measurement of the fiber) produced. An exhaustive index of parameters used in performance recording in sheep has been prepared (Owen, 1971; Plant, 1981).

The indexes listed in Table 16-1 are relevant to southern Australian conditions in terms of work published and local experience. They are still theoretical even in this case, however, and no actual targets are quoted because they have not been tested against a large bank of data to determine that they are reliable in a practical way.

BOX 16-3

Targets of Performance

LAMBING RATE
This is the number of lambs born per ewe exposed to the ram per breeding period. The target is 1.5 to 2.0 (varies with breed and the purpose of the flock). The percentage of ewes with twins varies from 20% to 80%, depending on the breed of sheep and management.

ESTROUS CYCLING INDEX
This is the percentage of females bred in the first 17 days of breeding period. The target is 100%.

BREEDING INDEX
This is the percentage of females bred (marked by ram) per breeding period. The target is 100% for a two-cycle breeding season.

LENGTH OF BREEDING PERIOD
The target is 35 days.

RAM:EWE RATIO
This depends on the age of the ram, breeding environment (pen or field), ram behavior, and whether synchronized estrus is used. The ratios are ram lamb, 1:20; yearling ram, 1:25 to 30; and mature ram, 1:40. In New Zealand a common range is 1:80 to 1:100. For estrus-synchronized ewes or out-of-season breeding, the ratio is 1:5 to 10. In the United Kingdom 3 rams with 120-150 ewes is common practice.

PREGNANCY RATE
This is the percentage of females pregnant per female exposed to the ram per breeding period. The target is 98%.

ABORTION RATE
This is the percentage of females that abort. The target is less than 2%.

WEANING RATE
This is the number of lambs weaned per female exposed to the ram per breeding period. The target is 1.5 to 1.7.

EWES WEANING LAMBS
This is the percentage of ewes that wean at least one lamb. The target is more than 95%.

AVERAGE DAILY GAIN
This is measured from birth to weaning and adjusted for sex and multiple birth. The target is 0.3 to 0.5 kg/day (dependent on breed and management of the flock).

AGE AT FIRST BREEDING/LAMBING
The target is 7 to 12 mo for intensive systems. Under extensive conditions, most replacements are first bred at 18 mo.

CULLING RATE
The target is 20%. The reasons for culling should be age, not chronic disease such as mastitis and footrot.

EWE MORTALITY RATE
This is the percentage of ewes that die annually. The target is less than 2%.

PERINATAL LAMB MORTALITY RATE
This is the percentage of lambs born alive that die from birth to weaning. The target is less than 5%.

STILLBIRTH RATE
This is the percentage of lambs born dead. The target is less than 2%.

MEAT PRODUCTIVITY
This is the weight (in kilograms) of lamb sold per ewe per year exposed to the ram or per hectare of land.

WOOL PRODUCTIVITY
This is the grease wool yield per sheep in the flock or per hectare of land.

Management Efficiency

An assessment of the percentage application of recommended techniques is worthwhile. The assessment can be made by measuring the rate of occurrence of specific diseases. Specific targets are not supplied for most of the indexes presented because there is such great variation among countries and breeds. Actual targets need to be developed for each locality; these should be based on known performance in pilot flocks and on general local information, which is usually hard data from field research (much of this is regionally based). The absence of such information makes target development less reliable.

Special Productivity Targets

Meat Production

In terms of lamb, the common denominator in most countries, there should be an annual turnoff of 150% of lambs related to the ewe flock, and lambs should average 40 kg body weight at 14 to 20 weeks of age off pasture. As with wool, however, the range of normal values is wide and is influenced by many factors, especially, in optimum feed situations, by the genetic makeup of the sheep. The period taken to reach the desired weight is also critical, but insufficient data are available to give any worthwhile figure. Grain-fed Dorset lambs can reach 35 kg by 120 days, and Suffolk lambs can reach 45 kg by 120 days. Under pasture grazing systems, rapid growth is also important to ensure efficient use of pastures. The target in lamb feedlots in the United States is an entry weight of 33 to 36 kg, a daily gain of 250 g for 60 days, and a final weight of 47 kg. The targets in intensive lamb feeding units are not as well defined, but a daily gain on milk replacer of 250 to 300 g to reach 36 kg at 16 weeks at slaughter time is reasonably satisfactory. With grain supplementation of ewes at pasture, many lowground U.K. flocks sell 40 to 44 kg twin lambs by 14 to 16 weeks of age. Singleton lambs can exceed 40 kg by 11 weeks of age.

Wool Production

There is a large variation among and within breeds of sheep in the weight of fleece and the quality of wool produced. These differences are further magnified by the quality and quantity of feed available and by geographical location. Thus quoting of targets is almost meaningless. However, the alternative is to derive an optimum figure based on the mean of a large mass of data collected in a specific area. Under optimum conditions, classes of merino sheep are capable of producing the following weight of clean wool each year:

1. Fine-wooled merinos: 19-μ diameter wool, 70s spinning quality, 3 kg
2. Medium-wooled merinos (Peppin strain): 21 μ, 60s spinning quality, 4 kg
3. Strong-wooled merinos (South Australian): 22 to 24 μ, 58 to 60s spinning quality, 9.5 kg

Longevity

Those sheep that survive disease and culling for poor productivity achieve the ultimate goal of "cast for age." In practice, this often means culling for dental faults, such as excessive incisor tooth wear or loss ("broken mouth") or uneven molar teeth wear with sharp points. The sheep is then unable to graze efficiently and is rejected because of its inability to maintain weight or produce wool. The age at which the teeth fade varies, depending on diet—especially the calcium, phosphorus, and fluorine intakes—and on the degree of contamination of feed with soil debris. On moderately rough pasture composed of native plants, the age at which ewes are culled is somewhere around 6 to 7 years. Dental wear is distinct from broken mouth. In some districts in New Zealand, for example, the incisor teeth of sheep are worn to gum level by 3.5 to 4 years of age. The

TABLE 16-1

Indexes For Recording Performance In Sheep

Parameter	Definition	Target
Reproductive index* = $\frac{\text{Lambs born}}{\text{Ewes joined per breeding period}}$		
Cycling index	% ewes mated in first 14 days of breeding period	65%-70%
Mating index	% ewes mated in complete joining	>95%
	(or % ewes that do not mate)	<5%
Lambing rate	% ewes mated that lamb	>95%
Abortion rate	% pregnant ewes that abort	<2%
Ewe death rate	% ewes dead per annum	< 5%
Twinning rate	% ewes with twins	
	Merinos	10%-20%†
	Romneys	80%
Lamb survival index: marking percentage	% lambs marked (docking of tails and castration) to ewes joined	
	Merinos	80%-100%
	Romneys	110%-120%
	% ewes that lose all lambs born	10%-20%
Miscellaneous: mating management efficiency		
Average age of ewes at first joining		18 mo
Percentage of rams to ewes in mating groups		2%
Length of joining period (6 weeks in autumn, 9 weeks in spring)		6-9 wk
Meat production in mutton flocks as measured by:		
Average body weight at weaning (related to age at weaning)		—
No. of lambs (body condition score or weight and age) plus number of surplus adult sheep sold per hectare		—
Actual weight of lamb or mutton sold per hectare		—
Wool productivity — indicated by wool yield by weight (quality and price quoted) per hectare and/or per sheep stock unit		—
Longevity expressed as:		
Percentage of deaths and culls per year in age groups		—
Percentage increase in flock size minus the reproductive index		—
Percentage of sheep sold as surplus to static requirements minus the reproductive index		—

*This is the most informative index, but is often not measurable because of lack of surveillance at lambing.

†The lower figure is for maiden ewes. Unless otherwise specified, the indexes are for merinos in Australia (Plant JW: Field investigations into reproductive wastage in sheep. In Postgraduate Committee in Veterinary Science, Refresher Course for Veterinarians No. 58: Sheep, Sydney, 1981, University of Sydney) and are for illustration only.

precise cause and pathogenesis have not been defined, but they appear to be related to soil ingestion and the use of improved pasture and high rates of stocking. Broken mouth refers to the loss of incisor teeth as a consequence of periodontal disease.

NORMAL REPRODUCTIVE MANAGEMENT OF THE SHEEP FLOCK

The normal reproductive management cycle of sheep is summarized in Table 16-2. The ewe is seasonally polyestrous, with estrous cycles usually commencing in late summer and continuing through until late winter, unless pregnancy intervenes. The mating season of sheep occurs during the period of decreasing daylight. British breeds of sheep transported to the Southern Hemisphere alter their breeding season to correspond to the reversal of the seasons, so that transported ewes come into heat during the months corresponding to their homeland spring. During the breeding season, the ewe shows cycles of 16 to 17 days. Although methods of manipulation of the photoperiod to induce estrus in sheep have been known for many years, they are generally impractical, expensive, and cumbersome. However, in many countries, melatonin is being used to advance the breeding season by 6 to 8 weeks. The duration of estrus ranges from 1 to 1.5 days, with an average of about 35 hours. The ewe is a spontaneous ovulator, and ovulation occurs 24 to 26 hours after the onset of estrus. The presence of the ram can reduce the duration of behavioral estrus and advance the time of ovulation relative to the onset of estrus. The breeding activity of ewes can be stimulated by the sudden introduction of intact or teaser rams after complete absence of at least 1 month before the normal breeding season. This helps in the advancement of the breeding season, which can lead to a financial advantage by the earlier production of lambs than with regular production systems.

The behavioral signs displayed by the ewe during estrus are few and consist primarily of remaining close to the ram and standing to be mounted. Mature ewes display ram-seeking activity when they are in estrus, so that contact between the sexes is not necessarily completely dependent on

TABLE 16-2

Normal Reproductive Management Cycle of Sheep

Time of Cycle	Management Procedure	Body Condition Score (BCS)
6-8 Weeks before breeding	Ram breeding soundness examination Plan adequate ram power to support needed ram:ewe ratio Assess and adjust ram rations if too fat or thin	Ram, 4.0
3 Weeks before breeding	Ewe breeding soundness examination Increase nutrition if ewes too thin Teaser rams in for ram effect during transition Vaccinate ewe for *Campylobacter* and/or *Chlamydia*, if indicated Drench for parasites, if indicated Plan for hormonal induction of estrus, if indicated	Ewes, 3.0 to 3.5
Breeding season (48 hours to 42 days)	Change color of marking harness every 14 days Calculate cycling and breeding index Continue level of nutrition through breeding period and first 3 weeks postbreeding	Rams, decrease to 2.0 Ewes, static
End of breeding season	Remove rams and put in teasers with marking harness to help detect cycling nonpregnant ewes (in season only)	
12 Weeks after ram first in or 7 weeks after ram removed	Pregnancy test using real-time ultrasound Sort according to open (cull) singles and multiples for optimum nutrition to placentas and fetuses Calculate pregnancy rate	Ewes, static or down to 0.5
100 Days' gestation	Increase level of energy and protein in ration, particularly in ewes carrying multiples and thin ewes (BCS ewes) Observe for abortions (fetuses, red vaginal discharge) and investigate as indicated	Ewes, static
30 Days before first lambing expected	Vaccinate ewes for clostridial diseases Drench for parasites, if necessary Shear or crutch, if necessary BCS and sort thin ewes for higher level of nutrition Observe for pregnancy, toxemia, abortion Prepare for lambing (facilities, vaccines, feed)	Ewes, static
Lambing	Close observation (minimum 4× day) to decrease stillbirths and early neonatal losses (hypothermia or hypoglycemia) For details see "Perinatal Lamb Mortality" section	

the ram's activity. In ewe lambs, the behavioral signs of estrus are usually weak and the duration of estrus is shorter than in mature ewes. Ewe lambs usually make no effort to approach the ram and may be reluctant to accept the service when he makes his sexual advances. Rams may show preference for mature ewes, and, in extensive operations, it is sound management to mate ewe lambs and two-toothed ewes separately from older ewes in a confined mating area in order to use active rams of small to medium size and to maintain a high ram:ewe ratio. Thus the detection of estrus in ewes in the absence of rams is difficult, with the exception that occasionally the estrus ewe moves her tail vigorously as part of a display pattern when she is with the rams.

At the start of the breeding season in sheep, it is only after the end of the first ovarian cycle that behavioral estrus is exhibited by the animal. The initial ovulations of the season and the establishment of corpora lutea occur at a silent heat. The progesterone produced by these first corpora lutea plays an essential role in sensitizing hypothalamic receptors so that the ewe becomes capable of responding subsequently to minute quantities of ovarian estrogen and of exhibiting the behavioral signs of estrus. The ewe of many commercial sheep breeds shows a clear nonbreeding season, whereas the ram remains capable of reproduction throughout the year, with a reduction in sperm output during the nonbreeding season and reduced fertility during periods of temperature extremes. The length of pregnancy is approximately 147 days, with some breed variation.

The ram has an important influence on the reproductive performance of the ewe. Fertility is directly related to the number of services, the number of spermatozoa deposited in the ewes, and the time of breeding relative to ovulations. In natural breeding circumstances the ewe may be bred several times. Ewes may also be served by more than one ram during estrus, particularly if the ratio of rams to ewes is more than 1:100 (Fayez and Marai, 1987). There is also the potential of some ewes being ignored by some rams. Sexual behavior in a flock is determined by social interactions among the males, with dominant and subordinate rams. This can lead to reproductive failure if the ram or rams that occupy the top positions in the dominance rating have reduced or total infertility.

The sudden introduction of rams in the early transitional period can stimulate the breeding activity of the ewes, and the estrus induced is known as the ram effect. The exposure of ewes to the ram only needs to last for 48 hours, rather than the 16 to 24 days formerly advocated for the ram effect. This allows one ram to be moved among several groups of ewes. The efficiency of the ram effect is usually measured under field conditions by the proportion of ewes that display estrus 16 to 24 days after introduction of the rams. The advancement of the breeding season is often 2 to 3 weeks before the breed's normal commencement. This tends to synchronize the ewes over a 10-day period starting after the introduction of teaser rams or rams on the other side of the fence, which synchronizes the ewes and does not compromise the fertility of the rams with overbreeding of early-estrus ewes. The puberty of ewe lambs may also be advanced by the sudden introduction of rams and leads to a high degree of synchronization at first mating. The results are dependent on breed, season of the year, and BCS.

The ratio of rams to ewes varies widely. For mature rams, the ram:ewe ratio is usually 1:40 to 50. In many flocks three rams are placed with 120 to 150 ewes, with each group of rams rotated after 17 days. Ram:ewe ratios need to be adjusted if ram lambs are used, for out-of-season breeding, or for any form of synchronized breeding. Rams can serve 10 ewes a day over a 4-day period or 8 to 10 ewes in 24 hours under field conditions when allowed access to ewes in active estrus (Fayez and Marai, 1987). Some rams whose sexual motivation was maintained by the provision of fresh ewes have ejaculated 11 to 17 times/day with adequate sperm counts still recorded after 6 days, whereas in other rams the number of sperm per ejaculate was reduced below the level believed to be adequate for fertilization. Decreasing the number of ewes bred from 100 to 25/ram can lead to more rams serving each estrus ewe and in a greater proportion of ewes being covered during the first 2 weeks of breeding. When synchronization is practiced in a flock, short-term endurance of the ram becomes more important and the ram:ewe ratio must be increased. In conclusion, the increase in ram:ewe ratio is associated with an increase in the lambing rate and lambs born per ewe of the flock.

Two daily peaks of mating activity have been identified—from 0400 to 0800 hours and from 1600 to 2000 hours, coinciding with sunrise and sunset. A high proportion of ewes also exhibit the onset of estrus at sunrise and sunset. During estrus, the optimum time for a ram to inseminate is 9 to 12 hours after the onset of estrus.

Health and Production Management to Optimize Reproductive Performance

Breeding Program

The breeding program and methods used depend on the objectives and production goals of the producer, the geographical location of the flock, the size of the flock, the degree of intensification of production, the breeds being used, and the facilities available. If wool is the major production objective, as it is with Australian merino flocks, the sheep are raised under extensive conditions and lambing occurs annually. If the number of lambs that are reared to market age is the primary goal, increase of the number of lambs born annually per ewe becomes the production objective and influences the breeding methods used. In some countries, lambs are marketed at 16 to 30 kg, primarily at Christmas and Easter for an ethnic market. These lambs are usually sold before weaning and may have been creep fed while nursing. Lamb feedlots in North America purchase weaned lambs at 4 months of age and feed them until they weigh from 40 to 50 kg. British breeds and their crosses under traditional methods of British husbandry produce annually, on the average, 1.7 lambs and one fleece. The seasonality of the common breeds of sheep means that their breeding season is limited to the autumn months.

The number of lambs born each year can be increased by two methods: increasing the number of lambs born per lambing and increasing the number of lambings per ewe annually. The increase in number of lambs per lambing is achieved by selecting for multiple litters or by using fecund breeds of sheep, such as the Finnsheep, Blueface Leicester, Romanov, Arcott, or, more recently, the Booroola merino. An increase in the number of lambings per ewe annually may be achieved by selecting extended seasonal breeds of sheep in temperate climates and by managing them in specific frequent or accelerated lambing production systems. More frequent lambing can also be achieved by using exogenous hormone therapy to induce and synchronize estrus or by using photoperiod manipulation through lighting control and melatonin administration.

Time of Year for Breeding

A breeding period should be selected at which the serving capacity and fertility of rams and the occurrence of estrus and fertility of ewes are at their highest. This means avoiding hot months (because high environmental temperatures

reduce ram libido, semen quality, and ewe fertility). There is a distinct preference for autumn over spring because of greater fertility. However, the breeding period must also be compatible with good nutrition of the ewe during late pregnancy and with lambing occurring at a time when lamb survival is maximal. This means not only a time of mild weather, but also that the stressful situation of lambing should occur at a time that is nutritionally appropriate for a good start in life.

Length of Breeding Period

In autumn, 5 weeks is a sufficient breeding period in a well-managed flock. In a spring breeding program, 8 to 9 weeks is recommended.

Management of Ewe Flocks

The management of ewe flocks in regard to their reproductive performance must emphasize a strong culling program, good nutrition, and avoidance of debilitating disease. The culling program should be directed toward performance, age, udder health, and inherited defects.

Genetic Selection for Reproduction

There is considerable variation among breeds in their rates of reproduction, largely because of differences in ovulation rate, the main determinant of fecundity, and, to a lesser extent, fertility at various seasons of the year, or length of the breeding season and lamb survival (Fogarty, 1984). Fecundity (litter size) ranges from about 1 to 1.2 in many Australian merino flocks to more than 2.5 in breeds such as the Finnsheep, Blueface Leicester, Arcott, and Romanov. These differences in fecundity among breeds are mainly an expression of differences in ovulation rate (Dyrmundsson, 1987). Ovulation rate sets the upper limit to the number of offspring produced per pregnancy and accounts for an overwhelming proportion of the genetic variation in litter size, both among and within breeds of sheep. If within-breed selection is the only available option for genetic improvement of prolificacy, the annual rate of genetic improvement in litter size can be doubled when the ovulation rate is used as the selection criterion. In the Booroola merino, mean litter size and ovulation rate are 2.5 and 4.2, respectively, which exceed those values for other merino strains. The Booroola offers the opportunity for a quantum increase in fecundity in one generation compared with slower improvement from within-flock selection. Genes with similar magnitudes are segregating in the Cambridge, Icelandic, and Javanese breeds (Hanrahan, 1987; Owen, 1988). Genetic material from prolific breeds, such as the Finnsheep and the Romanov, in which high prolificacy is not apparently the result of a single gene, has been used in many countries to raise the prolificacy of local breeds or as the basis of new composite breeds (Hanrahan, 1987). Substantial heterosis or hybrid vigor is also expressed for reproduction when crossbreeding is practiced and has been used to maximum advantage in lowground sheep production systems in the United Kingdom.

Reproduction is a complex trait and includes the components of fertility, fecundity (which incorporates ovulation rate and embryo survival), and lamb survival (individual and maternal rearing ability). There is genetic variation in each component and therefore room for genetic improvement. Ewe fertility may be affected by age at puberty, breeding season, and postpartum breeding interval in accelerated lambing systems (Fogarty, 1984). There is considerable breed variation for age at puberty, and the number of estrous cycles in the first breeding season, which is largely determined by age at puberty, is moderately heritable at 0.3 (scale 0 to 1). This should respond to selection if the lamb ewes reach sufficient live weight to attain puberty in their first autumn-winter. Age at puberty is largely influenced by body weight.

There is considerable variation among and within breeds in the time of onset of estrus activity and duration of the breeding season. In the extreme, many tropical breeds do not exhibit a distinct breeding season. Onset and duration of the breeding season are affected by breed and age, nutrition, and postpartum interval, and they can be modified by artificial day length, melatonin, use of the ram effect, and exogenous hormones. Variable and limited estrus and ovulatory activity outside the autumn breeding season restricts flexibility of breeding time and limits the reproductive rate of breedings outside the normal breeding season. This restriction limits the scope for more intensive accelerated lambing systems.

Fecundity is largely a function of ovulation rate and embryonic survival. There is considerable variation among breeds, with fecundity ranging from 1.0 to 2.5. Genetic variation for fecundity also exists within breeds and can be exploited by selection (Fogarty, 1984; Nitter, 1987).

There is increasing evidence of genetic differences among and within breeds for neonatal lamb behaviors that affect survival (O'Connor and Lawrence, 1992; Dwyer et al, 1996) and maternal rearing ability that is independent of parity (O'Connor et al, 1992). Selection within a flock for twinning and culling ewes for failing to rear a lamb at any lambing can increase lamb survival (Fogarty, 1984).

Frequent Lambing Systems

Traditionally, sheep lamb only once yearly with a 12-month lambing interval. However, where lamb is the major product sold and wool is of little significance, it may prove advantageous to lamb more frequently. Because of the costs of production, sheep are underused if they lamb just once; however, this statement fails to acknowledge seasonal growth of pasture and other crops. The breeding period in many sheep is 30 to 50 days, gestation is 147 days, and the period from birth to weaning is 60 days, all of which indicates that the complete reproductive cycle should not be more than 8 months. Thus a sheep could theoretically lamb three times in 2 years, although few commercial farmers could operate such complex management and husbandry practices. Although computer modelling of the biological aspects of estrus and reproduction in sheep has determined that for breeds of sheep with long potential breeding seasons, it is advantageous to breed ewes more frequently (Dzakuma and Harris, 1989a,b), few flocks outside University department farms operate frequent lambing systems.

Frequent lambing is lambing at intervals more often than once annually. With a gestation period of 5 months, the minimum theoretical lambing interval would be 6 months, but such an interval has not been achieved consistently, even with the use of exogenous hormones, because the average time necessary for uterine involution is up to 2 months. Increasing the number of lambings per ewe annually may be achieved by selecting aseasonal breeds of sheep and managing them in specific, frequent, accelerated lambing production systems (Hogue, 1987).

The most suitable breeds for frequent lambing are those with a long-duration breeding season, along with high prolificacy, in order to achieve high annual production (Tempest, 1983). In the United Kingdom the Finn-Dorset (Finnish Landrace × Dorset Horn), and in France, the Romanov and Prealpe-du-Sud, have been successful in frequent lambing systems (Tempest, 1983). The Dorsets, the

Polydays, and the Arcotts have also done well in frequent lambing systems tested at Cornell University, in Idaho, and in Guelph, Ontario, respectively. Early weaning at 4 to 6 weeks of age is practiced, followed by controlled breeding techniques using vaginal pessaries of a progestogen for 12 days and by the administration of pregnant mare's serum gonadotropin at sponge withdrawal.

The ewes are scored for body condition at weaning, and a diet is provided as necessary for about 2 weeks to ensure that they have a score of 3 at breeding. At 48 hours after withdrawal of the vaginal sponge, fertile rams are introduced at a ratio of one ram to 10 to 12 ewes. The rams are removed after the synchronized estrus and reintroduced 14 days later to breed at the first repeat heats, after which they are finally removed (Tempest, 1983).

The success of frequent lambing is influenced in large part by the level and pattern of nutritional management throughout the cycle and the level of knowledge and expertise of the operators. The premating level of nutrition is maintained for the first month of gestation. In midpregnancy it is critical to restrict feed intake so that the ewe maintains her body weight while ensuring controlled mobilization of body fat for fetal growth (Mellor, 1983). In late pregnancy increased feeding is necessary to achieve high lamb birth weights; to meet the energy demands of large fetuses, twins, and triplets; to promote udder tissue development; to prevent excessive mobilization of body fat in the ewe; and to prevent pregnancy toxemia. At approximately 3 months of gestation, the ewes are pregnancy-tested using ultrasound technology and barren ewes are moved into the alternate subflock and sponge treated. With frequent lambing systems, extended lambing seasons must be minimized, and induction of lambing with corticosteroids to control lambing is recommended. Lactational management to meet the needs of the growth rate desired in the lambs requires attention to the ration. Maximum milk output from the ewe is closely related to the level and type of dietary crude protein (CP) and the amount of energy provided. The optimum level of dietary crude protein is about 170 g CP/kg dry matter (DM) with a protein source of low degradability, and the diet fed at three times the maintenance level in terms of energy (Tempest, 1983). This still leaves the ewe in negative energy balance, and she would mobilize her body fat reserves to supplement her energy requirements. In later lactation, it is necessary in the frequently bred ewe to avoid excessive depletion of body reserves before rebreeding and to begin drying up the ewe by encouraging a greater solid feed intake by the lambs before weaning.

The levels of production performance in frequent lambing indicate that up to 2.7 lambs/ewe annually in the flock are possible (Tempest, 1983). In addition to the increased reproductive efficiency that may be achieved with a frequent lambing system, there are some other advantages:

1. More uniform supply of lamb throughout the year, which is an advantage to processors and retail markets
2. Increased efficiency of the use of facilities, such as lambing barns and feeding pens
3. More uniform yearly labor requirement
4. Spreading the risk of bad storms or unfavorable markets throughout the year
5. Providing producers with a uniform cash flow throughout the year

Twice per Year. If all ewes in a flock would breed the month after lambing, they could be managed on a 6-month basis. The flock could be divided to provide additional lambing periods throughout the year, and a uniform and consistent level of production could be achieved (Hogue, 1987). However, few ewes achieve this level of production in temperate zones, and the system is considered impractical.

Three Lambings in 2 Years. In this system the flock is divided into two subflocks, with one or the other lambing every fourth month. Each ewe is given the opportunity to lamb every 8 months or, if that is not possible, at 12-month intervals. The breeding and lambing schedule can be depicted over 24 months (Table 16-3).

January, May, and September are lambing months, although the schedule could be shifted to other periods provided the proper intervals are maintained. Lambs are usually weaned the second month after birth, and the ewes are bred 1 month after weaning their lambs. Because all ewes have an opportunity to lamb for a 12-month interval if they do not conceive for the 8-month interval, any ewes that do breed the first time represent an increase in efficiency over the 12-month period (Hogue, 1987).

Four Lambings in 3 Years. This is planned around a 9-month lambing interval, with four lambing periods per year. Each ewe is placed with the ram the fourth month after lambing and every 3 months thereafter until bred. January, April, July, and October are the lambing months; May, August, November, and February are the breeding months. This system could be combined with twice-yearly lambing so that ewes would have an opportunity to lamb after 6-, 9-, or 12-month intervals.

STAR System. The STAR system was developed at Cornell and is based on the need of accelerated lambing to coincide with the biology of the sheep and to fit with the calendar year (Hogue, 1987). If breeding and lambing could be coin-

TABLE 16-3

Month Breeding and Lambing Schedule

	Year 1												Year 2											
Month	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**	**D**
Flock A	L			B				L			B						L			B				
Flock B						L			B						L					B				L

B, Breed; *L*, lamb.

cident, overall management would be simplified. The STAR system solves these problems. With a gestation length of 146 days, half of a pregnancy is 73 days, which is exactly one fifth of the year. The calendar year contains exactly five sheep half-pregnancies, or five equal 73-day periods. Thus the annual calendar can be depicted in circular fashion and divided into five equal 73-day periods (Fig. 16-1). By breeding or lambing the first 30 days of a period, the remaining management tasks are immediately apparent. If a ewe lambs in period 1, she is bred in period 2 to lamb in period 4, to be bred in period 5, and so on. Each ewe can lamb five times in 3 years and complete the STAR. The five lambing periods per year have these advantages: (1) allow ewes to lamb five times in 3 years, which equals 1.67 lambings/ewe annually, (2) allow a uniform annual production of market lambs for a uniform supply and cash flow, (3) increase efficiency of utilization of facilities such as lambing areas, and (4) allow for the identification of ewes that not only breed out of season but breed following lambing in any season. The Cornell Dorset Horn (polled) flock has been managed on the STAR system for 4.5 years. Each year, more ewes lamb in the autumn and the average lambing interval decreases. The flock represents selected sheep because long-interval ewes are culled, sufficient STAR ewes have been identified to produce all breeding rams, and all lambs are sired by rams from STAR ewes. A comparison of the results of frequent lambing systems and a normal, once-yearly system is summarized in Table 16-4.

Prebreeding Management of Ewes

A breeding soundness examination is not possible in ewes, but BCS can be assessed, and examination of the udders can be performed whereby ewes with evidence of mastitis are culled. The incisor teeth of individual ewes should be examined for loss or uneven wear, which can adversely affect prehension and energy intake, even if they conceive and bear lambs. Investigations should be undertaken if more than 5% of ewes with normal dentition are found to have BCS below the target value. In most flocks, weaning lambs at 90 to 120 days allows 3 months for ewes to improve in body condition. It generally takes 6 to 8 weeks of good quality grazing to increase the BCS by one unit (five-point scale). Ewes in poor body condition have low estrus activity and conception rates (Grant et al, 1981).

The number of lambs born can be increased readily by increasing the ovulation rate. There are potential adverse economic consequences of multiple ovulations, including increased embryonic and early fetal losses (Dingwall et al, 1987) if ewe nutrition is not maintained for 4 to 6 weeks after the mating period. Ewe deaths may result from pregnancy toxemia if the flock is not managed correctly during late gestation, but such losses only occur in extensively managed flocks.

In merinos, the benefits of the extra lambs produced are offset by the reduced fleece weights of the breeding ewes and by the increased grazing pressure exerted by the lactating ewes and their lambs (White and Bowman, 1987) because

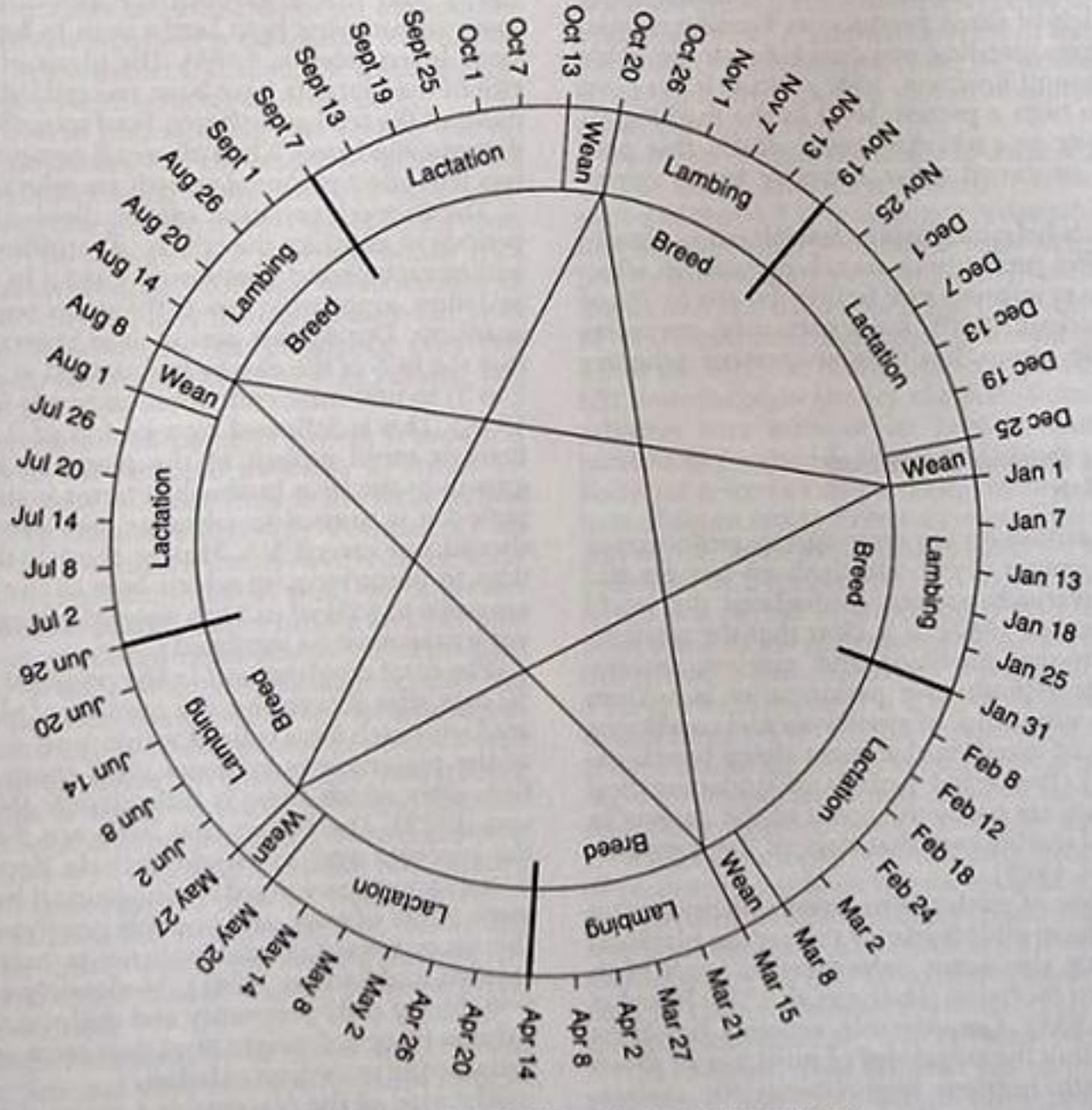

FIG. 16-1 Cornell STAR accelerated lambing system.

TABLE 16-4

Comparison of Frequent Lambing Systems and a Normal Once-Yearly System

Lambing Periods (per year)	Common Name	Lambing Interval (mo)*			Lambing/Ewe/Year		
		Bred 1st Exposure	Bred 2nd Exposure	Bred 3rd Exposure	Bred 1st Exposure	Bred 2nd Exposure	Bred 3rd Exposure
1	Traditional	12	24	36	1.0	0.5	0.33
2	2×/year	6	12	18	2.0	1.0	0.67
3	3× in 2 years	8	12	16	1.5	1.0	0.75
4	4× in 3 years	9	12	15	1.33	1.0	0.80
5	STAR†	7.2	9.6	12	1.67	1.25	1.00
6	CAMAL‡	6	8	10	2.0	1.5	1.20

*Assumes ewes are grouped and moved to the next group if they do not conceive at one breeding.
†Cornell STAR system (see Fig. 16-1).
‡Cornell Alternate Month Accelerated Lambing (CAMAL) system.

producers are not prepared to supply extra feed. However, in those sheep systems producing lambs, such producers definitely benefit from increased ovulation, implantation, and lambing rates. For wool-producing enterprises in southern Australia, the feeding of energy-based supplements to ewes before breeding to increase fecundity was evaluated using mathematical models of sheep production. Feeding supplements to ewes before breeding was concluded to be likely unprofitable (White and Bowman, 1987). While it has been speculated that too high a protein level in the flushing rations may contribute to early embryonic death, this phenomenon can be attributed more correctly to an energy deficit.

In flocks in which helminthiasis or fascioliasis is a problem, prebreeding and prelambing drenching with an effective anthelmintic may improve ewe fertility by 4% to 7% of lambs weaned (Mackay, 1980). Such preventive measures are fundamental to sheep health management schemes worldwide.

Nutrition of Ewes During Gestation and Early Lactation

The influence of nutrition on the reproductive performance of ewes has been a matter of concern to sheep farmers and sheep production research workers throughout the world (Gunn, 1983; Robinson, 1987). It is clear that the relationship between nutritional provision and nutrient requirements for optimum reproductive performance is seldom ideal because of the wide range of environmental conditions and the seasonality of breeding that most sheep breeds exhibit (Gunn, 1983). Prolonged periods of undernutrition during midpregnancy are partly the result of the decline in feed availability and quality over that stage of the reproductive cycle (Kelly et al, 1989).

Prolonged duration of moderate to severe undernutrition of ewes bearing twins in midpregnancy can reduce placental development causing significant reductions in lamb birth weight with increased mortality (Mellor et al, 1977; Rhind et al, 1980; Mellor, 1983). Considerable progress has been made in understanding the principles of nutrition of sheep and in defining their nutrient requirements for maintenance, pregnancy, and lactation (Russel, 1985).

The sensitivity of lamb birth weight, particularly in twins and triplets, to the ewe's plane of nutrition during late pregnancy is well known (Khalaf et al, 1979; Struber et al, 1979). It has been established that mortality rates are high in lambs with birth weights below the breed norm (Khalaf et al, 1979), and that after birth the absolute growth rates are lower in surviving light lambs than in heavier lambs of the same breed (Mellor, 1983). The plane of nutrition and the size of the placenta have been recognized as major determinants of the fetal growth rate. Fetal growth retardation in undernourished ewes has a placental component, and the factors that affect placental growth are relevant here.

The 21-week gestation can be divided into a number of periods to consider the effects of nutrition on reproduction within each period (Robinson, 1983). In the first month of gestation, embryonic loss is the main sequel to inadequate nutrition. During this period, it is generally recommended that the BCS of the ewe be maintained at 2.5 to 3.5 (scale of 1 to 5) to minimize embryonic and early fetal losses (Russel, 1985). This is followed by a period of 2 months in which there is rapid growth of the placenta, but during which growth of the fetus in absolute terms is still small. Over this period it is normal to advocate that losses in body weight should not exceed 5%. Finally, there is the phase from 90 days to parturition, in which gain in the mass of the fetus amounts to 85% of its birth weight; during this period nutrient intake must be increased.

Placental development in the pregnant ewe begins about 30 days after conception, the number of placentomes associated with each fetus is fixed at this time, and the total weight of the placentomes increases until about 90 days of gestation, after which there is little change (Mellor and Matheson, 1979). The factors that influence the ultimate size of the placenta and its weight include hormonal and nutritional factors, prolonged environmental heating of pregnant ewes, parity of ewes, and possibly genotype (Bell, 1984), but the most important determinant is nutrition of the ewe (Mellor and Murray, 1981). Moderately severe undernutrition during early pregnancy and midpregnancy significantly reduces placental weight at or near term and causes chronic intrauterine growth retardation.

The size of the placenta is a major determinant of fetal growth. In well-fed ewes, the fetal growth rate before 120

days of gestation is not correlated positively with placental weight, but fetal growth rate in the last 3 to 4 weeks of pregnancy is limited by the size of the placenta. Earlier placental influences on fetal growth are evident, however, when ewes are underfed. Placental weight and fetal growth rate are correlated positively during periods of maternal underfeeding, which starts before 90, at 95, or at 112 days of gestation (Mellor, 1983). During the first 90 days of pregnancy, placental growth is reduced when ewes are moderately underfed. Low-weight fetuses in ewes with placenta weights near the bottom of the normal range are affected with chronic and progressive hypoxemia and hypoglycemia, which affect fetal metabolism (Barlow et al, 1987). The consequences are fetal death during late pregnancy, fetal hypoxemia during parturition, premature birth, and a high perinatal mortality rate caused by hypoglycemia and hypothermia (Mellor, 1983; Barlow et al, 1987).

The extent to which ewes maintained on a fixed ration draw on their own body reserves in an attempt to meet the energy costs of pregnancy is determined by fetal weight (Mellor, 1983). In well-fed ewes, fetal growth rate remains constant until at least 120 days of gestation and decreases thereafter. However, its absolute growth rate increases markedly during the last 8 weeks of gestation, when fetal growth is most rapid, exceeding 100 g/day near birth. The growth rate among fetuses is highly variable, which accounts for birth weights ranging from 2 kg to over 7 kg. When ewes that have been well fed are severely underfed at any stage during the last 40 to 50 days of pregnancy, the fetal growth rate decreases within 3 days by 30% to 70%. This illustrates that the mobilization of maternal reserves is substantially less than fetal requirements and emphasizes the importance of ensuring a continuous supply of good-quality feed during late pregnancy. The larger the fetal burden, the more susceptible a ewe is to hypoglycemia during underfeeding.

Refeeding after severe underfeeding can reverse the reduced growth rate of fetuses, but the response depends on the duration of the underfeeding. If the period of underfeeding is 16 days or less, the growth rate increases when ewes are refed, but there is no change when refeeding occurs after 21 days of severe underfeeding. Moderate underfeeding of pregnant ewes for 85 days reduces the fetal growth rate irreversibly, and refeeding them in late pregnancy does not cause the fetal growth rate to increase but does prevent further decreases after 120 days.

The major consequences of prenatal growth retardation are on lamb survival. The neonatal mortality of lambs increases markedly in many environments as the birth weight falls below 3 to 3.5 kg (Khalaf et al, 1979). Compared with normal lambs, low-birth-weight animals have reduced insulation because of the smaller number of wool fibers, greater relative heat loss because of their larger surface area per unit of body weight, and a reduced capability to maintain heat production because of their lower fat and energy reserves. All these factors increase their susceptibility to environmental stress and reduce their ability to compete with normal-sized siblings. Underfeeding during pregnancy can also reduce available body lipids in lambs by about 47% and also decreases the lactose, lipid, and protein available in colostrum during the first 18 hours by about 50% (Mellor and Murray, 1985a,b). Newborn lambs have to draw on body reserves of glycogen in order to maintain heat production during the first 18 hours after birth, and thus depend heavily on colostrum intake and supplemental feeding to avoid hypoglycemia and hypothermia.

The effects of maternal nutrition on udder development and on the production and yield of colostrum and milk in ewes have also been examined (Mellor and Murray, 1985b; Mellor et al, 1987). In the last 30 days before birth, there is a marked increase in the rate of mammary tissue growth in the ewe. In well-fed ewes with one or two lambs, large volumes of colostrum accumulate in the mammary glands during the last few days of pregnancy and copious milk secretion begins soon after birth, with averages of 1800 to 2800 ml of colostrum and milk being produced during the first 18 hours (Mellor, 1987). Udder growth rates are proportional to fetal growth rates in that the greatest increase in udder weight occurs in the last 30 days of gestation and the weight of udder tissue is 30% to 40% of the total weight of the litter. Colostrum production is proportional to udder weight, and refeeding of ewes a few days before lambing fills the udder tissue present but does not increase udder tissue weight (Mellor, 1987). In underfed ewes, prenatal colostrum accumulation is reduced markedly, lactogenesis is delayed, and the total production of colostrum and milk during the first 18 hours averages about 1000 ml. Subsequently, in both types of ewe, milk production increases, reaching a peak about 1 to 2 weeks after birth. Underfeeding ewes beginning at 105 days of gestation can reduce the total yield of colostrum during the first 18 hours after birth by decreasing mammary tissue growth. Thus the prepartum accumulation of colostrum and its subsequent rates of secretion are reduced (Mellor et al, 1987). Improving the ewe's nutrition from 1 hour after birth can increase the secretion rates of colostrum between 10 and 18 hours (Mellor and Murray, 1985a,b).

The growth rate of lambs during the first few weeks of life is correlated positively with birth weight. Low planes of maternal nutrition during late pregnancy and early lactation are generally associated with low birth weights, milk yields, and postnatal growth rates, and high planes of nutrition with the opposite effects. A marked increase in the plane of maternal nutrition at birth can overcome the inhibitory effects on lactation and lamb growth rate of underfeeding in late pregnancy (Mellor, 1983).

At breeding time the aim is to achieve a body score of 3.0 to 3.5, which ensures maximum ovulation rate. For ewes with a BCS of 3.5 at breeding, it is desirable to allow them to lose no more than 5% of their body weight steadily, equivalent to approximately 0.5 to 1 unit of condition score during the second and third months of pregnancy. This mild degree of undernutrition enhances placental growth and establishes the basis for maximum fetal growth in the fourth and fifth months of pregnancy, the period during which the fetus achieves over 80% of its growth. During these final 2 months of pregnancy, there is a limit to the extent to which body fat reserves can be used, because excessive mobilization of depot fats as a consequence of inadequate dietary energy supply leads to pregnancy toxemia. In late gestation the optimum BCS ranges from 2.5 to 3.0. In contrast, early lactation is a period in which body fat can be safely used to meet some of the high energy demands of lactation. During this period, a loss of BCS of 1.0 (equivalent to 5 kg of fat for a 70-kg ewe at mating) is acceptable, and during lactation it ranges from 1.5 to 2.5. The replacement of the body fat that is used before the next breeding cycle is important in achieving a maximum ovulation rate and subsequently optimum reproductive performance (Robinson, 1983, 1987).

Winter shearing of pregnant ewes during the final 10 weeks of pregnancy has been shown to cause a significant increase in lamb birth weight. Shearing pregnant sheep at 8 weeks before lambing leads to a chronic increase in energy requirements, which are met by oxidizing body fat depots without risks of clinical ketosis (Symonds et al, 1986, 1988). Fetal growth is enhanced as a result of these metabolic adaptations.

The nutrient requirements for maintenance, breeding, pregnancy, and lactation of ewes have been catalogued (Agricultural Research Council, 1980, 1984; National Re-

search Council, 1985), and optimum feeding strategies for the breeding ewe can be formulated. The evaluation of the ewes' ration during late gestation by monitoring plasma concentrations of the ketone body 3-OH butyrate has been described with accurate guidelines provided (Russel, 1985), which have been used as the basis for flock nutritional advice during late gestation (Scott, 1988).

The achievement of optimum reproductive performance involves changing feeding strategies and adjusting the nutrient value of the diet as necessary throughout the reproductive cycle to meet the needs of the particular stage. The requirements for metabolizable energy begin to increase steadily above maintenance levels beginning at between 8 and 12 weeks of pregnancy and continuing into late pregnancy and lactation (Agricultural Research Council, 1980). During early lactation, when the energy requirements of prolific ewes exceed those required by the voluntary consumption of all but the highest-quality diets, the body fat reserves are used and then replenished toward the end of lactation, when milk yield declines, and in the period leading up to rebreeding (Robinson, 1987).

In contrast to the ability of the ewe, particularly in early lactation, to use body reserves when the intake of energy fails to meet her needs, there is little scope for sustaining production by drawing on body protein (Robinson, 1987). For example, lactating ewes can lose up to 7 kg of body fat during a 4-week period in early lactation, when energy intake is below requirements. For ewes on a low-protein intake, the maximum daily loss of protein was 26 g. Thus it is important to meet the protein needs of the ewe at all times during pregnancy, but especially during late pregnancy, for fetal growth, udder development, and colostrum production. The estimates for protein are also based on the important principle of distinguishing between the needs of the rumen microflora for rumen-degradable protein and of the host animal for additional undegraded dietary protein when rumen-degradable protein fails to meet those requirements; this represents the minimum protein needs of the animal. In practice the dietary allowances for late pregnancy and early lactation are higher than the sum of the rumen-degradable protein and undegradable protein.

The rapid growth of the fetus after 90 days of pregnancy requires an increased allowance of dietary energy, which can be met with concentrates if only hay is available. This is particularly true for ewes carrying twins or triplets. The daily dietary energy requirement of ewes of varying body weights and fetal number ranging from singletons to triplets has been described in conjunction with a monitoring program for dietary energy supply based on plasma concentration of the ketone body 3-OH butyrate (Russel, 1985). This system forms the basis of flock advisory visits made by veterinarians during late gestation in U.K. flocks. Correct nutrition during late gestation guarantees appropriate lamb birth weights despite litter size and sufficient accumulation of protective immunoglobulin in the udder.

Body Condition Scoring of Sheep. One relatively simple method of monitoring nutritional status is through BCS. BCS involves equating certain physical characteristics that are readily identifiable in ewes of different degrees of fatness with a particular score. A score is given on a scale of 1 to 5 according to the degree of fatness, which is defined by certain physical characteristics in the lumbar region. These are the prominences of the spinous processes of the lumbar vertebrae, the prominence of and the degree of fat cover over the transverse processes of the vertebrae, the extent of the muscular and fatty tissue below the transverse processes, and the fullness of the eye muscle and its degree of fat cover (in the angle between the spinous and transverse processes). The scale is defined in Box 16-4.

BOX 16-4

Body Condition Scoring of Sheep

SCORE 1
The spinous processes are felt to be prominent and sharp. The transverse processes are also sharp, the fingers pass easily under the ends, and it is possible to feel between each process. The eye muscle areas are shallow, with no fat cover.

SCORE 2
The spinous processes still feel prominent, but smooth, and individual processes can be felt only as fine corrugations. The transverse processes are smooth and rounded and it is possible to pass the fingers under the ends with a little pressure. The eye muscle areas are of moderate depth but have little fat cover.

SCORE 3
The spinous processes are detected only as small elevations; they are smooth and rounded, and individual bones can be felt only with pressure. The transverse processes are smooth and well covered and firm pressure is required to feel over the ends. The eye muscle areas are full and have a moderate degree of fat cover.

SCORE 4
The spinous processes can just be detected, with pressure, as a hard line between the fat-covered muscles in the area of the eye. The ends of the transverse processes cannot be felt. The eye muscle areas are full and have a thick covering of fat.

SCORE 5
The spinous processes cannot be detected, even with firm pressure, and there is a depression between the layers of fat in the position where the spinous processes normally would be felt. The transverse processes cannot be detected. The eye muscle areas are full, with thick fat cover. There may be large deposits of fat over the rump and tail.

In general, BCS of sheep is more useful and more readily undertaken than weighing. After training it can be repeated reliably by different operators on different farms. Ewe BCS and nutrition at mating are important factors affecting ovulation rate, and much of the variation among flocks in reproductive performance can be explained by nutrition before mating. Not only is it important to have ewes in good body condition, but it is also important to have the ewes on a rising plane of nutrition. Ewes with condition scores above 3 have a higher ovulation rate than ewes in condition score 2 or below (other factors being equal). Increase in condition score is beneficial, whereas loss is detrimental to the ovulation rate. To obtain a flushing response, a minimum period of 3 weeks' high-level feeding immediately before ram introduction is required. This is normally achieved by either providing good quality grazing or reducing the stocking density. This gives a 3-week carryover period during which time all of the ewes should be mated.

When investigating a problem of low lamb production, an important parameter to measure is the condition score of the ewes close at mating. The importance of feeding ewes during this period to achieve good condition scores and

some live weight gain cannot be overemphasized to sheep farmers.

Age of Ewes

The objective for age at first breeding of ewes for lamb production under intensive conditions is 9 months, but this trend has become much less popular in countries of the European Union since changes in farm subsidy payments. For most flocks under extensive conditions, the objective for age at first breeding of ewes is 18 to 19 months. Up to 6 years of age, the fertility index increases, so that there is a point in keeping ewes until at least this age if dentition and body condition are good. Other limiting factors are the increasing frequency with age of mastitis and appearance, in endemically infected countries, of certain viral conditions such as maedi-visna, scrapie, Johne's disease, and sheep pulmonary adenomatosis. Ewes are usually culled for age at 6 to 7 years. In merinos the fertility and lamb survival indexes reach their peak at about 7 years and the twinning index at about 8 years.

Control of Severe and Debilitating Diseases

Outbreaks of disease that have general systemic effects can be disastrous for a breeding program, and the control and prevention of common, serious diseases is part of an animal health management program. In southern hemisphere countries, if blowfly strike is likely, the sheep could be jetted before and during the breeding season. A decision on whether to administer anthelmintics should be based on history, clinical signs of parasitism, and fecal egg counts based on samples from 10 to 12 ewes. Suboptimum body condition or body weight gain may be the result of general or specific nutritional deficiencies, and the diagnosis and assessment of these should form part of the animal health plan. If ewes are affected by debilitating diseases, such as caseous lymphadenitis and chronic progressive pneumonia, their fertility is likely to be reduced greatly (Brown and Olander, 1987). Caseous lymphadenitis has been and continues to be a significant problem for the sheep industry in many countries. It is a common cause of the thin ewe syndrome (Gates et al, 1977), but not in the United Kingdom where the disease was first recognized in 1985. The control of other diseases that secondarily affect the fertility of sheep—and this includes most diseases—is presented in other texts (Radostits et al, 2000; Kimberling, 1988).

Estrous Synchronization and Induction of Out-of-Season Lambing

Hormonal Methods. Manipulating the estrous cycle of ewes involves techniques that artificially control the hormone status, either by the addition of extraneous hormones or by methods that can lead the ewe to alter her own hormone status, with the purpose of bringing groups of females into heat together in response to the treatment (Tempest and Minter, 1987). Whatever method is used, it must be simple and cheap, require minimal labor, have the same effect on all animals, and not interfere with sperm transport, reduce fertility, or have any side effects. Synchronization of estrus in sheep using progesterone sponges and pregnant mare serum gonadotropin (PMSG), regardless of the physiological state of the ewe or the time of year, is now a well-established technique (Tempest and Minter, 1987). However, because progestogen- and PMSG-treated ewes often have a variable response in terms of litter size with many ewes producing three or more lambs, and because mortality at and around birth is a major cause of lamb loss, adequate supervision at lambing time is a necessary management activity to ensure that the benefits of synchronized breeding are realized. Supervised care during the lambing period can be carried out more efficiently if the estrus-synchronized ewes are additionally induced to lamb in synchrony after injection of dexamethasone.

Manipulation of the progesterone status of the ewe is the principle behind control of estrus. The period of progesterone secretion can be reduced by the administration of prostaglandin, which causes regression of the corpus luteum and begins the return of the follicular phase and the return to estrus of all ewes treated from Days 4 to 14 of the cycle. Two injections 8 to 9 days apart cause cyclical ewes to be on heat 2 days after the second injection. However, because anestrus ewes do not possess an active corpus luteum, and because estrus control is desirable in anestrus ewes, prostaglandins are of no value in out-of-season breeding programs.

Lengthening the period of progesterone dominance is achieved by the extraneous administration of progesterone, which extends the luteal phase and suppresses follicular development so that, on synchronous removal of this negative feedback "blockade," the ewes rebound into a compact follicular phase followed by synchronized estrus. Polyurethane sponges impregnated with a synthetic progesterone are implanted intravaginally to release the progesterone through the vaginal wall. The technique involves the intravaginal administration by sponges of 30 mg flurogestone acetate or 60 mg medroxyprogesterone acetate for between 12 and 14 days to promote synchronized estrus in groups of ewes 2 days after sponge withdrawal. Follicle-stimulating hormone in the form of PMSG is necessary in seasonally anestrus ewes, either 2 days before or at sponge removal. Cyclic ewes normally exhibit estrus after sponge withdrawal without additional PMSG.

The interval from the end of progestogen treatment (sponge removal) to the onset of estrus is 36 hours, and from the onset of estrus to ovulation it is 21 to 26 hours, for a total of between 57 and 62 hours from sponge removal to ovulation. The general recommendation is to introduce the rams 48 hours after sponge removal, or for set-time AI at 56 hours (Tempest and Minter, 1987). Currently, in New Zealand, two intravaginal devices for providing progestogen therapy are being used: the polyurethane sponge impregnated with synthetic progestogen and the CIDR, a Silastic device impregnated with progesterone (Smith et al, 1989).

Ewes can be bred late in the breeding season so that they lamb in April and May to coincide with the plentiful supply of spring grass and to avoid the adverse weather conditions often encountered when lambing earlier. Passive immunization against steroid hormones can also be used to increase the ovulation rate in ewes that are bred in late November or December, when their ovulation rate and fertility are often below normal (Webster and Namaghi, 1990). Fecundin has been withdrawn from the market in the United Kingdom because of the highly variable response with a large percentage of ewes producing three or four lambs with an associated, very high, perinatal mortality rate. It is unlikely that this product will find application in many flock-breeding programs.

The hormone melatonin (Regulin) can be used to induce out-of-season breeding (Rajkumar et al, 1989), and more commonly to advance the breeding season by 1 month or so in pedigree flocks. Melatonin has also been used successfully to advance the breeding season of young ewes in the flock, producing a more compact lambing period. When appropriately timed, melatonin can advance the breeding season by about a month, and the majority of ewes lamb over a 2- to 3-week period (Haresign, 1990). It cannot overcome the seasonality of reproduction, however,

and is only effective during a limited period before the start of the natural breeding season. The ram effect forms an integral part of the melatonin treatment strategy. The objective is to bring the animals closer to the onset of a new breeding season with the hormone and then to use ram introduction at a defined interval after implantation, when the ewes should be responsive to the ram effect to promote a more synchronized mating pattern. It is important to ensure that ewes have been isolated from contact with rams for some time before implantation. Teasers can be used in combination with melatonin treatment, but the introduction of rams, whether entire or vasectomized, should not occur before 5 weeks after implantation (Haresign, 1990). Melatonin can also be implanted into or fed to yearling rams to prepare them for out-of-season breeding (Williams and Hanif, 1990).

The synchronization of estrus in ewes requires a different approach to ram management. A simple but effective paddock breeding system that is practical under most conditions can provide satisfactory results if the number of ewes per ram is restricted. The ewe:ram ratio can vary from 5:1 to 10:1. Conception rates were 87% to the first synchronized estrus with six ewes/ram, 73% to the first estrus with 12 ewes/ram, and 89% to the first and second synchronized estruses combined at 10 ewes/ram (Tempest, 1983).

Teaser Rams. The use of vasectomized teaser rams, although less versatile and less precise than the hormonal sponge, is helpful for shortening the lambing period and for encouraging ewes to start breeding a week or two earlier than they normally would during the transitional period (Henderson, 1985). Ewes that have been deprived of the sight, sound, and particularly the smell of rams for at least 4 to 6 weeks (late anestrus to early breeding season) respond to the presence of the male by ovulating within 3 or 4 days, but without any signs of behavioral (silent) estrus (Henderson, 1985). In a proportion of these ewes (40% to 60%), a true estrus with ovulation and a behavioral estrus occur after about 18 days after the introduction of teasers. In the rest of the flock the corpus luteum formed after the first silent estrus regresses prematurely, followed by a second silent estrus with ovulation and a corpus luteum that has a normal life span. These ewes therefore come into fertile estrus from around Day 23 after the introduction of teasers on Day 0. If fertile rams replace the teasers at about Day 14, the majority of ewes in the flock can be bred over an 8- to 10-day period from around Day 18 onward. Lambing can be reduced to 4 or 5 weeks, with the majority of lambing occurring over a 2- to 3-week period (Henderson, 1985).

The best teasers are rams of high libido that have had some previous breeding experience. Young mature rams that are to be culled for some reason are often ideal teasers. Males should be vasectomized well before the period of use and the vasa deferentes checked histologically. The vasectomized males must be double tagged for clear identification. Although vasectomized males can be tested for sterility by electroejaculation immediately before putting them with the ewes, this method is not fail-safe because some entire rams do not always ejaculate after such stimulation and a false-negative result may be obtained with potentially disastrous consequences.

Synchronization of Lambing

Because perinatal lamb losses constitute a major source of loss in sheep flocks, control of the time of lambing enabling maximum supervision would be beneficial. Several different corticosteroids have been used, but optimum treatment for an induced lambing is 16 mg of dexamethasone injected intramuscularly.

Parturition can be controlled using clenbuterol, which delays the onset of labor (Plant and Bowler, 1988), but this method has not proved popular. Ewes are selected for treatment on the basis of impending parturition—that is, filling of the teats, warmth in the udder, and swelling of the vulva. The drug delays parturition for at least 10 hours, which allows for the supervision of ewes at lambing to help reduce perinatal mortality. Advantages and disadvantages are weighed in Box 16-5.

Artificial Insemination

If it is desired to spread the influence of a sire or group of sires over a large population, AI of sheep has a significant part to play. Suitable techniques are available, and results with fresh semen are positive (Miller, 1981). Ewes are detected in estrus by teaser rams, usually vasectomized ones. Semen is generally collected by artificial vagina or, in some circumstances, by electrical stimulation. The semen is checked for quality by physical methods, diluted, and used immediately. Short-term storage for 24 hours at 2° to 5° C is used but is not universally favored.

The results are conflicting. Deep-frozen semen has a conception rate of about 50%, so it is unlikely to be used in ordinary circumstances. The application of nonsurgical AI in sheep has been inhibited by the anatomy of the ewe's cervix, in which the cervical canal is tortuous and narrow. For practical purposes this has limited the deposition of semen within the first fold of the cervix using a plastic pipette (Maxwell, 1984). Insemination is into the cervical canal, using a lighted speculum, with the ewe's hindquarters elevated and the forequarters downward to provide maximum viewability and to restrict movement. More recently pregnancy rates, comparable with laparoscopic insemination directly into the uterine horns, have been described for nonsurgical insemination methods that allow transcervical deposition of semen. Intrauterine insemination may be performed using a laparoscopic technique that locates the uterus, and the semen is injected directly into the uterine horns (Maxwell, 1984; El-Gaafary et al, 1987). Conception rates in ewes after intrauterine AI with ram semen can be compared with those results achieved after natural breeding. In general, it is recommended that not less than 100 × 106 spermatozoa per female be used for ewes at naturally occurring estrus and 200 × 106 for progestogen-treated ewes (El-Gaafary et al, 1987). If the semen has been frozen, the minimum number of motile sperm required is about 400 × 106 per female in vaginal insemination and only 25 to 40 × 106 in intrauterine insemination. The optimum time for insemination is midestrus, and two inseminations given at 12 to 14 and 23 to 25 hours after the onset of estrus have been recommended. In the fixed-time insemination method, estrus is not sought, and the timing of insemination is based on the time of sponge withdrawal in estrus-synchronized ewes that are inseminated 56 hours after sponge removal (El-Gaafary et al, 1987). Embryo transfer techniques have also been described (Wilmut, 1987) and are now offered commercially in many countries.

Pregnancy Diagnosis and Surveillance

Pregnancy Diagnosis. Knowing whether a ewe is pregnant has two principal advantages:

1. The identification of nonpregnant ewes makes for more efficient flock management, enables savings to be made on expensive prelambing feeding, and allows opportunities for increased financial returns by selling nonpregnant ewes when market prices are generally high. Information gained

BOX 16-5

Advantages and Disadvantages of Synchronized Breeding and Lambing

ADVANTAGES

1. Increased supervision of ewes in labor and then of newborn lambs reduces perinatal mortality. The majority of lamb deaths are caused by insufficient or delayed colostral intake, which are avoidable by supervision. Ensuring passive antibody transfer within the first 2 hours of life is critical not only as a source of energy but also to prevent development of bacteremia-septicemia, which constitute major causes of lamb losses in the form of bacterial polyarthritis, meningitis, enteritis, and specific diseases such as lamb dysentery.
2. Ewes can be fed in groups based on fetal number and stage of gestation-lactation.
3. Lambs can be weaned in even batches, replacements reared to adequate body weight for breeding, and slaughter lambs finished to specific requirements and timed to meet specific markets.
4. Ovulation can be predicted precisely, enabling the use of artificial insemination, the use of better rams (Sire Reference Schemes using Best Linear Unbiased Predictor [BLUP] analysis), and the development of embryo transfer for genetic improvement.
5. The use of resources such as buildings and especially labor can be planned, creating optimum use and avoiding excessive seasonal demands. This allows effective planning of part-time labor; 40% of the fixed costs of sheep production is labor, and 46% of the labor cost is directly associated with the management of lambing. In a 100-ewe flock, it is estimated that it requires 1.82 hours of labor at lambing time per ewe.
6. Flock health management programs can be planned to ensure optimum efficacy of disease prevention measures, such as vaccinations and anthelmintic treatments.
7. Early breeding of ewe lambs can be induced.
8. The forward planning that is possible by controlling the date of lambing some 5.5 months in advance must be attractive in large-scale systems of production.

DISADVANTAGES

1. The major disadvantages of synchronized breeding are cost and the need for more rams, until such time as an effective (non-surgical) sheep artificial insemination service unit can be developed commercially.
2. The ewe shows only single estrus, with no return to estrus if she does not conceive.
3. A major potential for problems is the premature induction of fetuses in the late stages of gestation, when it is building up its energy reserves. This entails a risk of weak and stillborn lambs. To avoid this problem requires accurate mating records and a high degree of management skill.
4. More skilled shepherding is required to cope with the potential flock problem of mismothering in a condensed lambing period.
5. More indoor lambing sheds and pens and more facilities for warming lambs are needed.
6. In general, more effort and careful planning and attention to details are required.

from pregnancy diagnosis should include the proportion of ewes pregnant with singles or multiples, the proportion of ewes in early and late pregnancy, the BCS of the ewe, and the condition of her udder at the time of the examination.

2. The determination of fetal numbers in pregnant ewes by ultrasonography has been undertaken routinely by many farmers in the United Kingdom and the United States over the past 10 years or so. The ability to determine fetal numbers between 45 to 90 days of gestation allows ewes to be fed during late pregnancy in relation to their nutrient requirements. Such feeding, in conjunction with late gestation sampling for 3-OH butyrate concentration (Russel, 1985) as part of a flock health plan, ensures appropriate lamb birth weights and increased survival potential of the lambs. Lamb mortality is closely related to birth weight (Barlow et al, 1987), with mortality rates in excess of 40% for low-birth-weight triplet lambs (Khalaf et al, 1979). Twin or triplet lambs from ewes fed as if they were pregnant with only one fetus have low birth weight and are likely to die because of excessive heat loss or exposure and poor immunoglobulin transfer predisposing to bacterial infections. In flocks in which all ewes are treated alike, those carrying more than the average number of lambs are also more likely to develop pregnancy toxemia in late pregnancy (Scott and Woodman, 1993; Scott et al, 1998). Although it is claimed that single lambs from ewes fed as if they were pregnant with multiple fetuses are at risk as a result of a prolonged and difficult birth, there are few data to support this supposition. Absolute fetal oversize is commonly encountered in purebred pedigree meat breeds, including the Texel and Suffolk breeds, but is much less common in commercial flocks where potential problems of extended duration second stage labor can be overcome by diligent supervision and timely intervention.

In any investigation of a suspected reproductive problem, the pregnancy status of the breeding ewes is an important piece of information. The following are considered necessary for pregnancy testing to be acceptable in sheep production (Bell, 1983):

1. Accurate (combined error rate of no more than 5% is necessary; this refers to ewes diagnosed pregnant but failing to lamb, and ewes diagnosed nonpregnant but subsequently lambed)
2. Fast (should be able to do about 1/min)
3. Labor efficient
4. Physically easy
5. Cost effective
6. Able to make a diagnosis in early pregnancy
7. Noninvasive

A wide range of ultrasonic, radiographic, manual, visual, surgical, biochemical, immunological, histological, and cytological techniques have been described for assessing pregnancy in ewes, and these techniques have been compared (Watt et al, 1984).

Ultrasonic Techniques. Numerous ultrasonic techniques are available for the pregnancy diagnosis of sheep (Watt et al, 1984), and the literature on the principles of ultrasonography in the pregnancy diagnosis of sheep have been reviewed (White and Russel, 1987). B-mode, real-time ultrasonic scanning is a rapid and accurate method for the diagnosis of pregnancy in sheep (Sprecher et al, 1989). After the user has had sufficient training to gain diagnostic expertise, 98% to 100% accuracy can be attained. Transabdominal ultrasonography should be conducted between 80 and 110 days after the beginning of breeding or 35 to 65 days after the end of a 45-day breeding period, ideally before 100 days or 14 weeks. This allows adequate time for different management regimens to be applied to nonpregnant, single-bearing, and multiple-bearing ewes during late pregnancy. During these gestational windows, the accuracy figures quoted as being acceptable are pregnant or not, 99%; empty, single, or multiple, 98%; and multiples defined as twins, triplets, or quadruplets, 96% to 97%. B-mode ultrasonography is able to discriminate fetal numbers during a 60-day window between 40 and 100 days of gestation. The predictive value for the diagnosis of a single versus multiple pregnancy is 90% to 100%. Ultrasonography is used most efficiently when a linear array or sector probe is placed in the inguinal region of a standing ewe (Sprecher et al, 1989).

If facilities and farm labor are adequate, rapid pregnancy diagnosis is a function of diagnostician experience, and not the rate at which ewes are brought to the operator for the examination. Ideally the ewes are restrained in a portable raised chute or race, which holds the ewe standing 880 mm above the ground (Watt et al, 1984). Rates of scanning vary from 80 to 150 or more ewes/hour, depending on expected litter size (White and Russel, 1987; Rowe and East, 1998). The experience of the operator is of great importance in ensuring accuracy. Prospective operators can be taught in a 1- to 3-day course. Newly trained operators are at first unable to scan successfully; their accuracy for determination of numbers of fetuses ranges from 70% to 100%. However, after a period of experience with the technique on approximately 500 ewes and an appraisal session with an experienced operator, the accuracy of the new operator is sufficiently high to be of commercial value to hill flocks and to low-ground flocks with limited housing (Logue et al, 1987).

Manual and Visual Procedures. Some manual or visual techniques are also possible, and their advantages and disadvantages have been reviewed (Watt, 1983b). In the pregnant ewe, after about 90 to 100 days of gestation, the udder is enlarged and a sticky secretion can be expressed from the teats. Abdominal distention is obvious in late pregnancy, and some experienced producers can divide ewes into early and late lambers on this basis. Because it is useful only for late pregnancy, it has limited application but is a useful adjunct to other methods.

Vasectomized rams with a paint-colored keel can be run with the ewes after removal of the rams to identify estrous ewes, which are then removed.

Surveillance of Pregnant Ewes. If the pregnant ewe flock is large enough, it is advantageous to divide it into groups with similar projected lambing dates. Vaccinations provided to pregnant ewes and directed at passive immunization of their lambs can also be given at a more exact time.

Pregnant ewes are especially subject to a number of problems for which special surveillance should be maintained (Box 16-6). During the last 6 to 7 weeks of pregnancy, the plane of nutrition of the ewes needs to be increasing, or at least maintained, to avoid pregnancy toxemia and also to promote lamb survival. As a general rule, ewes should gain 15 to 20 lb (7 to 9 kg) of body weight during this period.

BOX 16-6

Conditions of Pregnant Ewes that Require Special Surveillance

FAILURE TO CONCEIVE
If the rams are taken out of the flock before pregnancy is established in most ewes, this could lead to a serious drop in flock reproductive efficiency. Continuing to run vasectomized rams fitted with a harness and crayon markers with the ewes can detect estrus ewes.

ABORTION FROM ANY CAUSE
Because early abortion in many ewes may go unobserved, a single occurrence should stimulate close surveillance. This may be of particular importance if *Campylobacter fetus* ssp. *fetus* is the cause. Vaccination is recommended at the beginning of the outbreak to reduce the number of ewes aborting if the expected lambing is in more than 6 weeks. Alternatively, antibiotic therapy can be administered metaphylactically to reduce abortions.

PREGNANCY TOXEMIA
This is common during the last month of pregnancy, especially when the ewe is carrying three or more lambs* and the feed supply is declining.

HYPOCALCEMIA
Where the flock is not well supervised, hypocalcemia may cause deaths in late pregnant ewes that are suddenly moved onto fresh pasture, deprived of all feed during late pregnancy, transported, or run by dogs.†

*From Scott PR, Sargison ND, Penny CD: *Vet J* 155:197-2000, 1998.
†From Scott PR: *In Pract J Vet PostGrad Clin Study* 17:266-270, 1995.

More details on the nutrition of ewes during pregnancy are presented later in this chapter.

Prebreeding Management of Rams

The sheep industry is engaged in producing rams to be used as sires in other stud and commercial flocks. The following program can be used as a protocol when checking a ram for purchase and for maintaining ram fertility in a flock with a flock health program in operation.

Selection for Fertility

The known and suspected inherited defects of sheep are listed elsewhere. Those that are of particular importance to ram fertility are cryptorchidism and inguinal hernias. Of direct importance in fertility is the positive inheritance of twinning, a susceptibility to dystocia, and dental malapposition. It is probably wisest to select against testicular and scrotal abnormalities that are of unknown origin. For rapid genetic improvement, the average age of the ram flock should be kept as low as possible, which in pedigree flocks means the use of rams when 7 to 9 months old. However, the fertility of such young rams is often low and ewe numbers should be limited to only 15. In other age groups, com-

monly quoted figures are that 10% of rams are infertile at 4 years and 35% at 7 years.

Breeding Soundness Examination of Rams

Given 100% pregnancy rates, the maximum number of lambs produced by a flock of ewes is determined by the mean ovulation rate of the flock (Cameron, 1984). Various forms of reproductive wastage intervene to ensure that this potential lamb production is never achieved. The optimum use of rams involves keeping those sources of wastage that are attributable to rams to a minimum, using the least possible number of rams of the highest genetic merit (selection intensity). To achieve optimum breeding rates, the ability of the rams to breed and induce satisfactory lambing rates must be reliably predicted. The ram can contribute greatly to reproductive wastage by failing to inseminate all the available estrus ewes or by failing to achieve maximum lambing rates in those ewes that are inseminated. Unsatisfactory lambing rates in ewes that are bred can be the result of a low proportion of ewes that lamb (fertility), or a low number of lambs born per ewe lambing (prolificacy) (Cameron, 1984).

More attention should be given to the selection and breeding soundness examination of rams than has been done in the past (Buckrell, 1987). A standard breeding soundness examination developed after extensive field tests has been reported (Kimberling and Marsh, 1997). This routine examination can be undertaken quickly, yet accurately detects abnormalities of spermatogenesis and sperm storage and infection of the male reproductive system. The ram with superior reproductive ability can breed more ewes, which leads to an improved first conception rate, a lower early embryonic death rate, and an improved lambing rate with fewer weak or undersized lambs.

In surveys of the examinations of rams, approximately one third have recognizable abnormalities of the reproductive tract, with orchitis and atonic or hypoplastic testicles being most common (MacLaren, 1988). Most of these abnormalities are also detectable by careful clinical examination of the scrotum and its contents. Approximately one third of the rams have abnormalities of other body systems, with diseases of the feet being most common followed by broken mouth, broken horns, and pneumonia. It has been estimated that the proportion of infertile rams in the United Kingdom ranges from 3% to 10% (Barr, 1984). Generally, infertile rams do not constitute a serious problem in the flock, because rams of normal fertility are able to compensate for less fertile rams in the group. However, an individual ram assumes much greater significance if it is dominant and prevents other rams from working or, if on hill ground, it collects and protects a group of ewes. Breeding in small groups or hand mating may also result in problems when using individual rams. In a 5-year survey of one Scottish Blackface flock, the routine examination of all rams resulted in the elimination of a 17% level of infertility, with an increase of 2.3% in the lamb crop (Barr, 1984).

The details of examination of rams for breeding soundness have been published (Memon, 1983; Ott and Memon, 1980). The working efficiency of a ram depends on libido, ability to breed, and the production of semen of satisfactory quality and quantity. Ill health or lameness may profoundly affect each or all of these criteria. A complete breeding soundness examination of rams includes a clinical history of the group of rams, the general clinical examination of body systems other than the reproductive tract for evidence of clinical disease or other abnormalities, examination of the reproductive organs, semen evaluation, and the serving capacity test (Galloway, 1983). The purpose of a breeding soundness examination or ram fertility test is to identify those rams that are unsound for breeding, which can range from 15% to 25% of the average ram flock, and to identify those highly fertile rams that can be used most efficiently in the flock (DeBlockey, 1983, 1984).

Six to eight weeks before the breeding season begins, a physical examination should be made of all rams, followed by the bacteriological examination of semen in rams with abnormal palpatory findings. During the physical examination, the presence of other diseases such as pizzle rot (infectious posthitis), which may affect ram fertility, can be identified. These include local abscesses caused by *Corynebacterium pseudotuberculosis*, psoroptic and chorioptic mange, mycotic dermatitis of the scrotum, blowfly strike, and lice and ked infestation.

The rams need to be in good body condition (about 4.0) at the start of the mating season if they are to stand up to the intensive hard work of breeding 50 ewes in a 5-week period. In one report of 160 rams examined, only 37% were in ideal condition, 50% were in acceptable condition, and 12% were in poor reproductive condition (Galloway et al, 1981). Bad feet, poor body condition, and poor teeth are commonly found, with testicular degeneration, epididymitis, and preputial injury being the most common findings in the genitalia.

At the time of examination, the feet should be trimmed, anthelmintics administered if necessary, and blood samples taken for brucellosis testing. The rams should also be shorn, if required. All wool on the scrotum should be removed carefully. The ration should be adjusted if the ram is in poor condition. Legume hay, or other supplements with a high level of protein, should be avoided because it predisposes to pizzle rot.

Additional measures in some countries include shearing the rams twice a year with the aim of having about 3 cm of wool at breeding. Insufficient wool leads to lack of insulation. Unnecessary driving during the breeding season is to be avoided and, if possible, well-shaded paddocks should be provided. Fat, heavily wrinkled, and shorn rams are the most susceptible to infertility caused by heat stress. Conversely, extreme weather conditions in hill areas may lead to fine-wooled sire breeds, such as the Blueface Leicester, not searching out estrus ewes.

Reports on the reproductive behavior of rams (Fowler, 1984) and on the relationships among semen quality, quantity, and fertility of the flock have been reviewed (Cameron, 1984).

Clinical History of Rams. A full history of an individual ram or group of rams should be taken before the clinical examination. The breed, age, identification, origin, management, nutrition, illnesses, and previous reproductive performance should be recorded. A clinical history of a ram can assist in the interpretation of abnormal findings on clinical examination.

General Clinical Examination. Body systems other than the reproductive tract are examined for evidence of disease or abnormalities that might interfere with breeding or that might be a potential source of disease for the ewes or other rams. Each ear tag is identified, and the mouth, teeth, and eyes are examined. The BCS of each ram is recorded. Poor condition scores (score 2 or below) for the majority of rams in the stud indicates malnutrition or other management problems such as poor parasite control, which must be reviewed carefully. Individual rams in poor body condition may indicate a chronic infectious process such as caseous lymphadenitis, chronic respiratory disease, and other focal bacterial infections. The breech, the legs, and the feet are examined. All abnormalities are recorded and interpreted, if possible, and further diagnostic work performed, if required.

Examination of Reproductive Organs. Scrotal circumference is the most useful predictor of ram fertility and can be measured readily by farmers at breeding sales. Although there can be marked seasonal variations in the scrotal circumference of rams (Mickelsen et al, 1982), these measurements are used as guidelines approximately 2 months before commencement of the breeding season; thus consideration of the influence of season (Memon, 1983) should not prove problematic. Australian studies have indicated that the minimum scrotal circumference for a ram to be introduced to 50 ewes is 24 cm. In eastern Australia more than 95% of rams have a scrotal circumference larger than 30 cm, which is considered the optimum required for breeding 100 ewes (DeBlockey, 1983). The Society of Theriogenology has provided guidelines for optimum average scrotal circumference for rams according to varying body weights and breeds; the values range from about 24 to 40 cm, depending on the breed, age, and weight of the rams (Mickelsen et al, 1982). In the United Kingdom the scrotal circumference for adult rams is recommended to be 36 cm or greater, with 40 cm desirable in pedigree stud rams because of the high heritability of this trait. Similar selection criteria have been quoted by U.S. workers (Rowe, 1998).

Scrotal circumference is directly related to sperm concentration in semen, sperm motility, percentage of morphologically normal sperm, first-service conception rate, and lambing rate. Replacement ewes from rams with above-average testicular measurements have higher ovulation rates and reach puberty earlier.

The ram is restrained in the standing position, and the maximum scrotal circumference is measured with a cotton tape measure. The scrotum and its contents are carefully palpated. The head and tail of each epididymis are palpated for any swellings. The testicles must be freely mobile and feel firm and turgid but not hard. In general, rams without palpable abnormalities do not require semen collection and evaluation.

Epididymitis is a major cause of infertility in the ram in many countries where *Brucella ovis* and *Actinobacillus semini—Histophilus ovis* are the organisms of most importance (Cottrell, 1985). If there is clinical evidence of epididymitis, a semen evaluation, semen culture, and complement fixation test may be necessary to reach a diagnosis. Once a diagnosis of *B. ovis* infection is made, regular complement fixation tests are necessary to identify carriers in the flock and to eradicate the infection. Other organisms that have been associated with epididymitis in virgin lambs include *Actinobacillus* sp. and *Haemophilus somnus (Histophilus ovis, Haemophilus agni)* (Bulgin et al, 1990). Rams with palpable lesions of epididymitis usually produce semen of poor quality (Bagley et al, 1984), but some affected rams produce good-quality semen but can be identified readily by the presence of large numbers of white blood cells on microscopic semen examination through the use of negative phase contrast. Ultrasonographic examination of the scrotum, testicles, and epididymes can provide very useful information concerning gross lesions, but this examination may prove too involved for routine examination of large numbers of rams under field situations. The use of an autogenous, multivalent, adjuvant vaccine containing *Actinobacillus* sp., *H. somnus (H. ovis)*, and *B. ovis*, and long-term feeding of low dosages of antibiotics have been evaluated for the control of lamb epididymitis in large purebred flocks (Bulgin et al, 1990). There is some indication of a reduction in the incidence of clinically affected rams.

The penis is exteriorized to ensure that the urethral process is normal. The prepuce and the penis are examined for evidence of infectious balanoposthitis, which can cause reduced reproductive performance because of pain and scarring to the extent that the ram cannot protrude the penis (phimosis).

Serving Capacity Test. Many behavioral and physiological components interact during breeding, but the single most important factor affecting conception is the achievement of insemination. Serving capacity is defined as the number of services achieved by the ram in a specified breeding situation. It is highly variable among rams, ranging from 1 to 25 services in a 33-hour pasture breeding period (DeBlockey, 1983, 1984). It can be measured either in the breeding pasture or in a yard test designed to predict service ability in the breeding flock (Galloway, 1983). The higher the serving capacity of a ram or group of rams, the more ewes that become pregnant at each estrus. High-serving-capacity rams achieve a higher pregnancy at each estrus than medium- or low-serving-capacity rams because they mount more of the estrus ewes and actually breed more of the ewes they mount (DeBlockey, 1983, 1984). High-serving-capacity rams also achieve a higher fertilization rate because they serve more of their estrus ewes and serve each ewe more times than medium- and low-serving-capacity rams (DeBlockey, 1983). Ewes served once, twice, or three times have pregnancy rates of 64%, 76%, and 93%, respectively.

Mature ewe flocks bred by high-serving-capacity rams also have a higher proportion of lambs born in the first 17 days of lambing than when bred by the medium- and low-serving-capacity rams. Only about 50% of ewes bred to poor-serving-capacity rams lamb after a 6-week breeding period. High-serving-capacity rams are also more effective than lower-serving-capacity rams for the breeding of maiden ewes, which normally are timid, do not seek out rams, and have a shorter estrus period compared with mature ewes. The use of high-serving-capacity rams can also lead to an increase in the twinning rate (DeBlockey, 1983). However, published data relating to ram service capacity must be kept in context. Few farmers evaluate ram service capacity, because in most situations the pregnancy rate achieved after 17 days of the breeding season generally exceeds 90%. Palpable abnormalities of the testicles-epididymes and infectious disease such as virulent footrot are more important considerations.

In the yard test for serving capacity, ewes are restrained in service crates fixed around the perimeter of a large yard. In large flocks, 10 or 12 service crates are set up around the perimeter of a large yard and 10 to 12 rams are put in with the ewes. The rams to be tested are sexually stimulated by allowing them to watch other rams mounting the restrained ewes for about 10 minutes. The stimulated rams are then placed in the yard with the ewes and the number of services the rams achieve in 20 minutes is counted. Rams serving zero to one ewe are poor-serving-capacity rams and make up 5% to 10% of the flock. Medium-serving-capacity rams complete two or three services, and high-serving-capacity rams serve four or more times in 20 minutes.

DeBlockey (1983) has recommended testing the flock rams annually to detect and cull the 20% of unsound rams and to assign a mating potential based on serving capacity and scrotal circumference. Serving capacity testing has been evaluated primarily in adult rams of varying and unquantified experience. A large proportion of rams purchased from breeder flocks by commercial breeders, however, have their first breeding experience at 18 months of age (Purvis et al, 1984). The use of the test may not be economical in young rams, because rams initially sexually inactive may become active in a second test.

Semen Evaluation. Semen can be collected by either electroejaculation or artificial vagina, and standard methods for the evaluation of semen are available (Galloway, 1983).

The repeatability of samples collected by electroejaculation is low, and rams should not be condemned based on a single unsatisfactory test result. Semen collection by artificial vagina is the preferred method, but not all rams elect to serve the restrained ewe. The semen should be examined for motility and density, the details of which are available elsewhere. Where appropriate the ejaculate should be cultured and smeared for *B. ovis*.

Ram:Ewe Breeding Ratio. Sheep are usually bred in groups or flocks, and it is considered normal to breed 33 to 100 ewes/ram (Fowler, 1984). The use of 1.5% to 2.0% high-quality rams provides a safe guideline for the proportion of rams to be bred to ewes. The higher percentage of 2% of rams should be used for maiden ewes. Variations in this ratio can cause major changes in breeding behavior. As the number of ewes per ram increases, the total number of mounts and services are increased and more ewes are mounted and bred. However, the number of services per ewe decreases in both pen and pasture situations. The amount of time taken for the rams to serve all the estrus ewes increases, and the number of rams breeding each ewe tends to decrease. As the number of ewes per ram exceeds 100, there is increasing competition among ewes and there are reductions in the services and mounts per ewe, number of ewes served, and flock fertility. As the number of ewes per ram falls below 30, and as the number of rams in the syndicate increases, there is increasing competition among rams (Fowler, 1984).

A summary of the recommended ram:ewe ratio follows:

Ratio	Parameter
1:100	Prolific breeds, mature rams, or flat ground (merinos)
1:40-50	Mature rams, other breeds
1:30	Hill flocks, mature rams
1:25-30	Yearling rams
1:20	Ram lambs
1:5-10	Synchronized ewes; mature rams

In general, for optimum results, mature rams are used at a concentration of 2% to 2.5% of the total ewe population. Young rams in their first season breed fewer ewes, and a concentration of 4% is recommended. A similar concentration may be needed on sparsely populated farms to ensure that the rams can locate the ewes in estrus.

Monitoring Ram Performance

The efficiency of the rams can be gauged by the use of a ram marking (breeding or mating) harness. A number of different rams can be monitored in a flock by the use of colored crayons in the harness. The same device can be used to indicate different time periods by using crayons every 2 weeks. The lighter colors are used first, followed by the darker colors. In the first 3 weeks of breeding, the rams should be marking all ewes, but in the second 3 weeks, the numbers being bred should be less than 10%. A harness ensures identification of those rams that are working, the percentage of the offspring, and the identity of those ewes that are bred on the same day. It is of great practical value in flocks in which anestrus is likely. If identification of those ewes that are showing estrus but that are not to be bred is the objective, vasectomized rams may be used. Failure to mate may result from anestrus in the ewe or failure of the ram to perform. The technique is not likely to be applicable in the field unless plenty of labor is available, because the flock needs to be examined at least once each week to record raddling and to allow adjustment of the harness. Changing the colors avoids confusion about which marking is latest. Changing colors every 2 weeks is a little easier on the color range if a 6-week breeding period is contemplated.

If possible, the ewes that are marked as being served during a particular period should be kept as a group so that at pregnancy diagnosis, they are all at approximately the same stage of pregnancy. It is essential that ewes retain their identification and that an accurate record of events for each ewe be kept.

Ram Effect

The introduction of rams to anovular ewes induces ovulation in the ewes within 6 days; this is known as the ram effect (Pearce and Oldham, 1984). The presence of the rams increases the secretion of luteinizing hormone, which leads to the induction of ovulation, but the factors predisposing to the introduction of rams are not well understood. The effect occurs in seasonally and lactationally anovular ewes and can be used to induce puberty in ewe lambs. The ewes must be in the anovular transitional period and must have been isolated from rams visually and pheromonally for at least 1 month before they ovulate in response to the reintroduction of the rams. The effect is a powerful and inexpensive method for controlling the time of sheep breeding and is an integral part of the reproductive performance of flocks bred in the spring. The ram effect is applied on a practical basis by introducing vasectomized or epididymectomized rams with marking harnesses to anovular ewes in order to advance the onset of the breeding season. Breeders have reported improved lambing rates and prolificacy resulting from the introduction of teasers during programs of induction of estrus cycles in noncycling ewes using exogenous hormones.

Diagnosis and Management of Reproductive Inefficiency

Criteria

The low rate of reproduction in commercial sheep flocks is a prime target for a flock health management program. The rate of loss is high and has not improved significantly for many years. There are two parts to the problem:

1. Failure to produce one or more live lambs by every ewe bred, presented as reproductive inefficiency in this section
2. Loss of a full-term lamb in the perinatal period, presented in the next section as perinatal mortality

Because the subject is complex and because there is a great deal of information about it, it is necessary to discuss the problem in a structured way, related to the way in which it is encountered in the field. Therefore it is described from the point of view of a reproductive inefficiency problem brought to us by a farmer in the ordinary course of practice. The same technique is used for handling a problem that begins to develop in a flock under a flock health management program. The final aspect of this discussion is the flock health program that should be instituted to avoid wastage caused by disease, but at a cost less than the benefit derived. Such programs vary widely from place to place, and even from time to time, depending on the profitability of the sheep enterprise.

It is assumed that, as with other herd health management programs described elsewhere in this book, the program must automatically assess itself so that the benefits of its operation are continually under surveillance.

The major criteria for assessing reproductive efficiency in a sheep flock are the following:

1. Percentage of ewes exposed to the rams that lambed at term
2. Average number of lambs born alive or dead per ewe exposed to the rams during the breeding period
3. Number of lambs weaned per ewe exposed to the ram during the breeding period

These criteria are influenced by the following indexes of reproductive performance:

1. Breeding index: the percentage of ewes marked by the ram during the breeding season
2. Pregnancy rate: the percentage of ewes exposed to the rams that are pregnant at pregnancy diagnosis 80 to 100 days after the beginning of the breeding season
3. Lambs born alive: the number of lambs born alive per ewe exposed to the ram during the breeding period
4. Length of breeding season: the number of days over which the rams were allowed to breed the ewes
5. Observed abortion and stillbirth rates

If the problem is failure to produce a lamb at birth, the following modes of reproductive failure are then considered:

- Failure to breed (ewe or ram)
- Failure of conception (ewe or ram)
- Early embryonic death (ewe problem)
- Abortion
- Combinations of any of the above

In flocks in which complete records are kept and good field observations have been made, it is usually possible to make an accurate diagnosis quickly. The following is a discussion of techniques of assessment, a description of the individual errors encountered, and how to correct them.

Techniques of Appraisal

The diagnostic procedure for deciding in which mode the specific error lies in any problem of flock reproductive inefficiency has been described frequently (Fig. 16-2). A more detailed account, suitable for field research, is also available (Moule, 1965). Special techniques can enable the appropriate decisions to be made.

Farm Profile. This includes construction of a history of the problem plus a description of the managerial and physical resources that may be important in causing the problem. On a well-managed farm, good data are available that can be analyzed, as discussed below. In others, it may be necessary to use approximations from limited records. If neither are available, it may be necessary to create a data file prospectively by collecting data for 1 or more years. Suitable categories for analysis of the data are shown in Box 16-7.

Examination of the Flock

Breeding Soundness Examination of Rams. This topic is presented earlier, in the section dealing with the maintenance of reproductive efficiency in the flock.

Physical Examination of Ewes. The BCS of the ewes should be assessed at weaning and again about 2 months before breeding so that there is time to supplement their diet to regain condition, if necessary. Special attention should be paid to the presence of a group of thin ewes among a flock of better-conditioned ones; the presence of a high percentage of such ewes in the flock may indicate a heavy parasite infestation, old ewes, Johne's disease, poor dentition, or inadequate feed supply. The information on BCS of ewes is presented in the section dealing with the maintenance of reproductive efficiency in the flock.

Accurate Head Counts of Ewes and Lambs. These are basic and absolutely essential, especially at lambing. If they are carried out whenever the sheep are worked, irrespective of the reason, they provide a repeat monitoring of the size and composition of each flock. Because the data recording

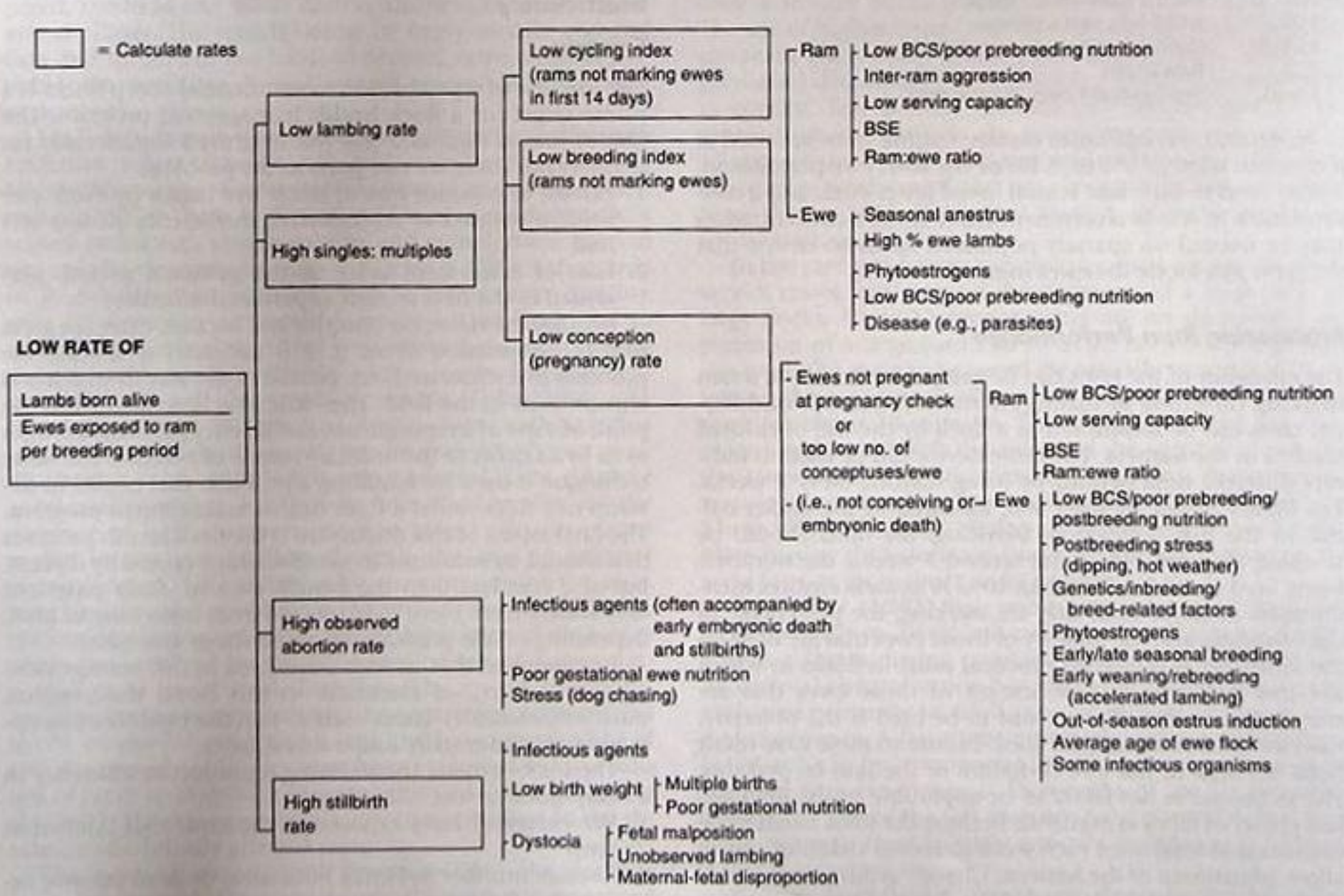

FIG. 16-2 Investigation of low rate of lambs born alive. *BCS,* Body condition score; *BSE,* body soundness examination.

and analysis on sheep farms must be based on flocks or subflocks, their accurate identification is essential at all times. The means of identifying the group may be by colored ear tag or by fleece brand.

Identification of Lactating and Nonlactating (Wet and Dry) Ewes. Under extensive flock management, the classification of ewes as soon as lambing is complete into groups indicating whether they have had lambs is known as the wet-dry classification but is more accurately referred to as lactating and nonlactating ewes. The latter classification is used here to avoid unnecessary confusion. If the classification of ewes can also include the year of birth of the ewe, which is easily achieved by a colored ear tag, the fate of the ewe can be decided on the spot. The recommended classifications are as follows:

1. Lactating ewes (wet-wet; ewes that have lambed and are now lactating). They have a lambing stain down the back of the udder. The udder is full and the teats are clean and large. Milk is readily expressed from the teats.
2. Nonlactating ewes (wet-dry ewes; ewes that have lambed but have lost their lamb[s]). A lambing stain is evident. The udder is at first large and full, but within a day the teats are dirty. Within a few days, involution of the udder begins but some secretions may be expressed for periods up to 2 months, with the secretion gradually becoming clearer and more viscous.
3. Nonpregnant ewes (dry-dry ewes; ewes that have not had a lamb this season). They have no lambing stain, are in good condition, and have no udder development with small teats.

Necropsy Examination. Necropsy examination is most valuable in attempting to determine the cause of death in newborn lambs. Such examination of infertile ewes is usually unrewarding.

Diagnosis of Mode of Reproductive Efficiency

The diagnosis of mode of reproductive efficiency is shown diagrammatically in Fig. 16-2. The scheme includes the use of techniques that may not always be available on commercial sheep farms. Without them, the questions cannot be answered. Because the questions also cannot be answered retrospectively, the investigation must be a prospective one. The modes of inefficiency—and thus their methods of detection—can be summarized (Box 16-8).

The failure of ewes to mate is not a common problem in adult merino ewes (Edey, 1969; Cannon and Bath, 1971), although it can occur (Restall et al, 1976). However, it is a significant occurrence in maiden ewes. The more common problem is a failure of fertilization or maintenance of the pregnancy.

Diagnosis of Failure to Breed. The decision to be made is between anestrus in the ewe or inability to breed by a ram.

Ewe Anestrus. During the natural breeding season, the most important single factor affecting the occurrence of estrus in ewes is nutrition. A dietary deficiency of total energy is manifested by a depression of ovulation rate or of fertilization and implantation. The result can be a decrease of the rate of mating to 70% for the first 2 weeks of the breeding season. The management response is to "flush" the ewe with supplementary feeding before the breeding period (Tassell, 1967a).

Determination of the nutritional status of sheep can probably best be done by BCS as described earlier. It should be emphasized that there is so much variation in body weight and fertility relationships among breeds and in different locations that any attempt to establish fixed standards would be futile. There is a special need to ensure adequate feeding of ewe lambs.

The occurrence of estrus also varies with the season, independent of nutritional status (Moule, 1965). This is most marked in merinos and merino crossbreeds, which come in heat regularly in autumn, although they breed in any season of the year in various geographic locations. Some breeds

BOX 16-7

Categories for Analysis of the Data

GEOGRAPHIC ANALYSIS
Lamb-marking percentages on different farms

EWE FLOCK PERFORMANCE
As displayed by different age groups (e.g., ewe lambs versus mature ewes), indigenous versus introduced ewes (ewes brought in), nutritional status, culling policy (e.g., culling for age, lamb production, wool production), shearing, dipping, drenching program

RAM MANAGEMENT
Based on purchasing policy (age, origin, time of introduction to flock, shearing, dipping, drenching program), breeding policy (including number of rams/100 ewes, switching rams halfway, length of breeding period, time of year, prebreeding teasing, breeding as singles or as groups), culling policy (culling for age, fertility, serving capacity), breeding soundness examination history

BOX 16-8

Summary of Modes of Inefficiency

Failure of ewe to breed: no raddle mark is present from ram harness.
Failure of ram to breed: only some of the rams in the group have bred some of the ewes; both are identified by raddle marks from the harness. (Note that if all rams have low fertility, it is impossible to differentiate these first two modes.)
Failure of ram to inseminate: the mark of color unique to a particular ram is not seen, there is a reduced number, or single ram breeding groups are using the harness, with the subsequent ram successful.
Failure of conception: there are normal interestrus periods as indicated by ram harness marks, with different colors every 2 weeks. If out of season, this can only be assessed by a pregnancy test or by not lambing.
Early embryonic death: there are long interestrus periods as indicated by ram harness marks, with different colors every 2 weeks. When rams cease marking, conception may be assumed and rams are withdrawn. To determine that ewes do not return to estrus, vasectomized rams should be run with the ewes.
Abortion: the aborted fetus is picked up, the retained placenta is seen, and there is a bloody vulval discharge.
Stillbirth: lambs are born dead.
Neonatal mortality: see the "Perinatal Lamb Mortality" section.

such as the Blackface and Down types are seasonally anestrous, independent of nutritional status. There is also a seasonal influence on the number of ovulations occurring at one time, so that a higher proportion of twins is likely to occur in merino ewes bred in the autumn than in spring. The differences are significant, with the respective fertility indexes being 95% in autumn and 78% in spring.

Ram Impotence. Painful conditions of the hind feet of the ram may prevent proper mounting and interfere with successful breeding activity. Inter-ram aggression among rams that have not been socialized before breeding can contribute to a low breeding index. Poor nutritional status and an insufficient ram population may also reduce ram activity. The more important causes of ram infertility are discussed in the next section.

Diagnosis of Cause of Failure to Establish Pregnancy. This includes failure of fertilization and implantation and early embryonic death.

Ewe—Failure to Conceive. Except for the infectious diseases, which cause abortion and embryonic death and are discussed elsewhere, there are few known specific causes of failure to establish pregnancy, such as high ambient temperatures and genetic influences (Moule, 1965). Anatomical abnormalities of the reproductive tract of infertile ewes have been described (Dobson and Davies, 1989) but these conditions are not prevalent. Nutrition and fertility relationships are unclear. However, embryo survival is greatest in ewes fed a full maintenance diet. The ingestion of estrogenic substances in subterranean clover and other plants is the best-known cause of poisoning, which may result in a failure to establish pregnancy in 70% of ewes and cause further losses of lambs at parturition (Tassell, 1967b).

Ram—Failure to Impregnate. Rams contribute significantly to infertility in sheep flocks, largely because of infectious diseases that affect their reproductive tracts. In addition, there are environmental influences. Rams show highest libido in the autumn, and they may be relatively infertile in hot summers, especially if they are not acclimatized. Libido also tends to be low in late winter and spring, especially in British breeds of sheep. High environmental temperatures can also cause seminal degeneration. Because of the relative frequency of fertility breakdown in rams (5% to 10% is not remarkable in year-old rams and 35% may be impaired at 7 years), an examination of the rams before mating periods is desirable and recommended (Ott and Memon, 1980).

Further examination is necessary if a diagnosis of infertility is suspected or a more accurate evaluation is required. Collection of semen by electroejaculation is a standard procedure, and examination of the semen makes possible a judgment on semen quality and the probable state of fertility. The bacteriological examination of semen has considerable merit, and serological examination for *B. ovis* is a standard procedure. The specific diseases associated with ram infertility are presented in other books.

There are many other diseases that can, by their local or systemic effects, cause temporary or permanent infertility in rams, such as blowfly strike, parasitism, and footrot. During any physical examination of a ram, the presence of a local dermatitis—for example, that caused by mycotic dermatitis, or mange—would be noted as a possible cause of infertility and its prevention recommended. The scrotum is obviously important, but so are the feet, entropion, or infections of the eyes; a badly undershot jaw, preventing good prehension, can adversely affect body condition and reproductive efficiency in rams that have normal genitalia.

Diagnosis of the Cause of Abortion. Abortions in sheep are often unrecognized unless outbreaks occur or unless sheep are brought together in late pregnancy and aborted fetuses are seen in the yards. The clinical signs of abortion in flock include the following: (1) ewes separated from the remainder of the group and showing uterine discharges before the expected date of lambing, (2) aborted fetuses seen when pregnant ewes are yarded, (3) lambs or fetuses born still enclosed in the fetal membranes, and (4) in some flocks, there may be an increase in the number of dry ewes in the flock, with no apparent increase in perinatal mortality or evidence of abortion. In most cases, the ewe does not exhibit any signs of clinical illness before or after the abortion. However, abortion resulting from certain *Salmonella* serotypes often causes severe illness, often death. With early abortions, such as can occur with toxoplasmosis, there may be no clinical evidence of abortion, no vaginal discharges, and no evidence of fetal membranes; producers may interpret this as failure of the ewe to conceive except that the ewe has only one raddle mark.

Abortion in sheep refers to the expulsion of a fetus before it is capable of independent life, usually before 135 days of gestation. Parturient deaths are full-term lambs that were alive at the beginning of lambing but died during lambing. Surveys have indicated that in most flocks, up to 2% of pregnant ewes may abort and no specific agent can be determined. A higher rate should prompt an investigation because of the importance of infectious agents as causes of abortion in sheep (Dennis, 1975).

The common causes of infectious abortion in sheep are campylobacteriosis caused by *C. fetus* ssp. *fetus*, enzootic abortion of ewes caused by *Chlamydia psittaci*, toxoplasmosis caused by *Toxoplasma gondii*, and salmonellosis caused by *Salmonella abortus-ovis* and other types, such as *S. montevideo*, *S. typhimurium*, and *S. dublin*. Less common causes include *Listeria monocytogenes*, *Ehrlichia phagocytophilia* (tickborne fever), and *Coxiella burnetii* (Q fever). Viral disorders include border disease infection and Akabane disease as well as louping ill.

Enzootic abortion caused by *C. psittaci* is the most commonly diagnosed cause of abortion in sheep in the United Kingdom, based on material submitted to diagnostic laboratories (Aitken et al, 1990). Monitoring for serological and clinical evidence of the disease forms part of the ADAS Sheep and Goat Health Scheme and the Premium Health Scheme for Sheep of the Scottish Agricultural Colleges. Fresh placentas and lambs should be sent to the laboratory (with disposable gloves) because of the zoonotic nature of the disease. Transmission occurs at the time of abortion and ewes that have aborted should be tagged with the date of the abortion and isolated for a minimum of 6 weeks. All placentas not sent to the laboratory should be destroyed by burning. Ewes that have aborted should not be used to foster female lambs.

Oxytetracycline is effective against the organism, and the use of long-acting oxytetracycline 6 weeks before the expected lambing date can maintain pregnancy in some infected ewes. The disease can be controlled effectively through the use of a live attentuated strain of *C. psittaci* commercially available in Europe.

Toxoplasmosis as a cause of abortion in sheep is being recognized with increased frequency. It is commonly associated with cats, and spaying female kittens, while protecting the grain and other feed from contamination, and adding monensin to the ration of the ewes may prove helpful control measures. Effective control of toxoplasmosis in flocks is achieved by vaccination through the use of a live concentrated aqueous vaccine containing tachyzoites of the S48 strain of *T. gondii*.

Toxins have not been identified definitively as abortifacients, but the evidence against fungi growing on *Romulea bulbocodium* (onion weed), or the plant itself, is convincing.

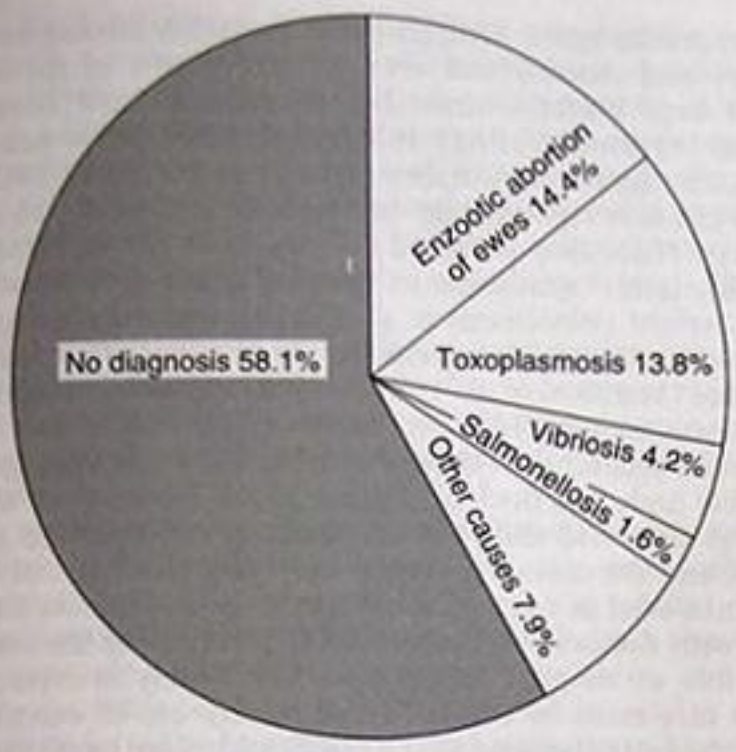

FIG. 16-3 Causes of ovine fetopathy. (From Linklater KA: *Vet Rec* 1:30-33, 1979.)

BOX 16-9

Procedure for Investigating Abortion in a Flock of Sheep

1. Visit the flock, obtain as much history as possible pertaining to the abortion problem, and establish a case definition. Is this really an abortion problem or a stillbirth problem? Attempt to characterize the abortions according to time of gestation, number of fetuses per ewe, and whether abortions occurred in a cluster over a short time or were spread throughout the prelambing period. The pattern of distribution may indicate whether an acute infection occurred in a group of pregnant ewes in a short time. Determine the age group of ewes affected. The incidence of abortion may be higher in certain age groups (e.g., ewes carrying their second crop of lambs in the case of chlamydial abortion). A differential diagnosis list of possibilities should be created to guide the veterinarian in the pursuit of a specific causative diagnosis. The characteristics of the most common causes of abortion are available in standard textbooks of sheep medicine and other publications.*
2. Collect as many fetuses and fetal membranes as possible and submit them to a diagnostic laboratory. Necropsy often allows a field diagnosis to be made, which then can be confirmed by submitting appropriate specimens.
3. Based on the suspected infectious agent, perform serological testing of all ewes that are known to have aborted and on a percentage of ewes that have not aborted and are considered normal.

*Such as (1) Plant J: Abortion in sheep. In Postgraduate Committee in Veterinary Science, Refresher Course for Veterinarians No 141, Sheep Medicine, Sydney, 1990, University of Sydney, and (2) Linklater KA: New developments in health control: management and health control. In Marai IMF, Owen JB, editors: *New techniques in sheep production*, London, 1987, Butterworths.

Other fungal toxins (e.g., from *Claviceps purpurea* and *Aspergillus fumigatus*) are quoted as causes of abortion. Abortion caused by infection with fungi, as in cattle, is not recorded in sheep.

Investigation of Abortions in the Sheep Flock. A major problem with obtaining a specific causative diagnosis of abortion in sheep is the low rate of submissions of aborted material from the flock. As a consequence, 50% to 60% of abortions may not be diagnosed by the laboratory (Linklater, 1979) (Fig. 16-3).

The procedure in Box 16-9 is recommended for the investigation of abortion in a flock of sheep.

PERINATAL LAMB MORTALITY

Magnitude of the Problem

Perinatal lamb mortality is one of the major factors in the impairment of productivity on sheep-raising enterprises around the world (Gumbrell, 1980; Gumbrell and Saville, 1986). When lambs die shortly after birth, not only is the opportunity of the ewe to reproduce lost for a year, but perinatal deaths reduce the volume of lamb for sale and reduce the number of surplus sheep for sale by the enterprise. Death loss is one of the most important factors associated with productivity (Fiss et al, 1991). It also reduces the options for selection in breeding programs and for culling to increase flock productivity, and it decreases the options to adjust flock structure for flexibility in management (Alexander, 1984).

The extent of perinatal lamb mortality varies from about 5% to 70% but averages from 10% to 20%. In an Australian survey of merino breeders, 28% of flocks lost 15% to 24% of lambs, 18% lost 25% to 34%, and 5% lost 35% or more (Alexander, 1984). It is also suggested that lamb mortality based on marking percentages changed little during the previous century. In southern Queensland, where most lambs are born during the spring, field surveys of merino flocks found perinatal lamb mortality rates ranging from 9% to 20% (Jordan and LeFeuvre, 1989). A major cause of reproductive wastage in most years in that same area was the loss of lambs from birth to lamb marking (Jordan et al, 1989).

In the United Kingdom the annual perinatal lamb mortality rate has been quoted as 15% or greater by numerous studies (Whitelaw, 1976; Eales et al, 1983; Barlow et al, 1987), with some authors quoting figures as high as 25% (Hindson and Winter, 1990).

In a 10-year survey of a large sheep enterprise of 177,000 sheep in Peru, of which 40% were breeding ewes, mortality during the first 3 days of life was 3.6%, and for the period from 4 to 30 days mortality was 0.5% (Ameghino et al, 1984). Mortality averaged 4.3% for the first 30 days of life, which is substantially lower than that described in Australia, where lamb mortality is usually about 15% to 20%. The low rate for perinatal mortality in lambs in Peru may be attributed to the excellent management conditions under the pastoral-shepherd system employed on this cooperative. Management practices were designed to provide as high a level of health care, nutrition, parasite control, range management, and husbandry as technically possible. In Australia, by comparison, higher death losses occurred in commercial sheep enterprises under extensive management conditions. Weak lamb syndrome, accidents, injuries, and starvation were the leading causes of mortality. Approximately 86% of mortality occurred in the first 3 days of life when nutritional, environmental, and management factors leading to weak lambs and starvation accounted for about one third of total mortality. Infections (22%), accidents (22%), and stillbirths (16%) followed in order of importance. During the remainder of the first month of life,

deaths from infections predominated, accounting for 60% of mortality from 4 to 30 days.

In sheep flocks that are housed at lambing time, and in which surveillance of ewes and the provision of timely assistance in cases of dystocia are possible, neonatal mortality of lambs can be minimal. In fact, almost all lambs can survive if given adequate obstetric assistance, warmth, and colostrum and milk. But questions of economics, expected incidence of multiple births, likelihood of cold, wet, windy weather during lambing, and sheep farmers' diligence determine the measures taken toward attaining these objectives. When lambing under average conditions, the percentage of lambs surviving until weaning can be as low as 70% to 80%.

Dennis (1972b) has quoted an estimated loss of 20% of all lambs born in most countries before weaning. In Australia, 80% of these deaths occur during the first few days of life; the immediate and delayed parturient deaths are discussed below. A survey of range flocks in the United States showed that there is a mortality rate of 23.5% between birth and weaning, and that 73% of these deaths occur during the first 5 days of life (Safford and Hoversland, 1960). Over a 5-year period, on average, about 26% of lambs born at the University of Minnesota Agricultural Experiment Station died before weaning, with 72% dying in the postparturient period (Yapi et al, 1990). Surveys in Canada have indicated that lamb mortality is about 14% (Dore et al, 1987). In Zimbabwe, 15% of lambs were recorded as dying before 16 weeks of age, with 70% of losses being caused by managerial errors (McKenzie and Grant, 1976).

In southern Australia, the average estimated neonatal lamb loss in a predominantly merino population was 15% to 20% (Dennis, 1974), but losses as high as 70% of ewes losing all their lambs were recorded (Plant et al, 1976). English estimates of loss were 12% (Boundy, 1979), and Scottish estimates varied from 5% to 15% (Houston and Maddox, 1974) in milder climates but up to 20% to 25% in hill sheep, mostly from starvation and exposure (Watt, 1980). New Zealand studies (Gumbrell, 1980; Gumbrell and Saville, 1986) have shown that an average mortality of 8% to 10% of newborn lambs was composed of death from starvation in 39% and exposure in 28%; 76% of lambs had lesions caused by dystocia. Of these deaths, 6% occurred before parturition, 33% during parturition, and 61% after parturition. A Norwegian summary showed an overall death rate of 9.7% in housed flocks from birth to 5 months of age, with 46% of these deaths occurring in the perinatal period of days 1 to 28 (Lutnaes and Paus, 1981).

High losses are usually associated with single causes, but there is a core level of about 15% that has not been amenable to reduction without an input of labor or capital, which most producers regard as unacceptably high.

Patterns of Mortality

Alexander (1984) reviewed the patterns of neonatal lamb mortality that recur in many flocks. Most deaths occur in the first few days of life, which is a reflection of the transition from a dependent intrauterine life to an independent extrauterine life. Mortality is typically related to birth weight by a U-shaped curve in which mortality is lowest at a weight between 3 and 5 kg; however, the optimum weight for survival depends on the breed and body weight of the ewe because these birth weights are a generalization. Mortality usually increases with litter size, a relationship that is associated with a decline in birth weight as the litter size increases (Khalaf et al, 1979; Barlow et al, 1987).

The relationship between age and parity of the dam are not clear. Mortality can be as high as 33% in primiparous ewes and is minimal over the next four or five pregnancies before it rises again. Differences in mortality among various breeds and crosses, and even among strains of the same breed kept under comparable conditions, have been reported (Alexander, 1984). Inbreeding, both of the dam and lamb, can increase mortality (Wiener et al, 1983). Delayed birth can vary significantly among breeds (Woolliams et al, 1983a). There may be breed differences in the incidence of "weakly lamb" syndrome in spite of relatively low average birth weight (Woolliams et al, 1983b), and inbreeding can be associated with an increase in the incidence of infectious diseases (MacLeod et al, 1983). Losses of lambs from crossbred ewes are usually lower than from purebreds, and birth losses associated with dystocia in Australian Dorsets are invariably high. In a flock of English polled Dorset ewes, about half of ewes had difficulty in lambing and required assistance, and the overall perinatal mortality was 9%, but 55% of lambs died as a result of birth injuries and anoxia associated with dystocia (Wilsmore, 1986) indicating the important role of diligent supervision and timely intervention. Great care must be exercised not to rely on, or accept, all published data because many publications are based on relatively discrete sheep populations, often single flock studies performed over one season only. Veterinarians must collect reliable data from the best farms in their practice and use these performance results as realistic targets. These targets can be adjusted as improvements in flock performance result from the implementation of the flock health plan.

Relative Importance of the Individual Causes of Neonatal Mortality

The principal causes of neonatal mortality are those causing hypothermia in the lamb: excessive heat loss because of a high chilling factor in the environment, and low heat production caused by prolonged birth, immaturity, and starvation (Eales et al, 1982a; Alexander, 1984). However, it is not possible to provide general figures because individual causes have varying importance in different environments. Especially important is whether the sheep are housed and, if not, whether they are farmed intensively with close surveillance, or whether they are run under extensive pastoral conditions, where such surveillance is not possible.

One of the most exhaustive surveys of the causes of neonatal loss in sheep was completed in Australia (Dennis, 1974, 1975). Under those extensive conditions of sheep production, starvation, dystocia, predation, and exposure accounted for most of the deaths. Infectious diseases were a relatively minor cause of mortality. Even in housed ewes in the United Kingdom that were pastured after lambing, the losses were about 12%, most of them at birth and on the first day of life, with starvation and stillbirth representing almost half the deaths and neonatal infection the next largest category (Purvis et al, 1979). In northern Scotland, where the sheep run at pasture all year, the overall death rate has been recorded as 14.2%, again with stillbirths, starvation, and exposure as the most common causes, accounting for over 50% of deaths (Johnston et al, 1980). In New Zealand the most common cause of death in singles was dystocia caused by high birth weight; in multiples the most common cause was starvation and exposure as a result of lower birth weight. Many of these losses could be avoided by ultrasound determination of fetal number during midpregnancy and appropriate late gestation nutrition. Lambs of birth weight of 3.5 to 5.5 kg and from 4- to 5-year-old ewes survived best (Dalton et al, 1980). These data are invaluable to veterinarians when formulating a flock health plan with their clients to reduce neonatal losses. In Queensland (Australia), exposure to a high environmental temperature was a common cause, with small lambs (about 2.5 kg) being the most sus-

ceptible (Stephenson et al, 1980). In two highly prolific Booroola crossbred flocks and a Romney flock, dystocia was the predominant cause of death for single lambs, whereas for large litters, prenatal and prolonged birth causes were of increasing importance (Hinch et al, 1986). A study of a commercial lowland sheep flock in England over a 2-year period revealed that the major causes of lamb mortality were stillbirths, weak, underweight lambs, and climatic stress (Purvis et al, 1985).

In a 2-year survey of perinatal lamb mortality in 28 housed Michigan sheep flocks, the major causes of mortality were dystocia-stillbirth, starvation and hypothermia, pneumonia, and abortions, which accounted for 50% to 75% of perinatal losses (Rook et al, 1990).

In summary, the major causes of neonatal lamb mortality are low birth weight lambs that do not suck sufficient colostrum immediately after birth, which renders these lambs susceptible to cold exposure, hypothermia caused by cold exposure under adverse weather conditions, and various bacteraemic conditions. Birth injury alone, and as a predisposing factor to hypothermia and starvation, is reported as an important factor contributing to perinatal mortality in singleton lambs where there is poor flock supervision. Birth injury is not a major contributing factor to neonatal lamb losses in multigravid ewes managed under intensive conditions.

The numerous factors that jeopardize newborn lambs have been identified. It is evident that lamb survival depends on the integration and success of physiological activities in four crucial areas (Mellor, 1988):

1. Initiation and completion of the birth process
2. In utero preparation of the lamb to face the challenge of a free-living existence
3. Preparation of the ewe for her postnatal nutritive role
4. Establishment of a good ewe-lamb bond

A detailed clinical, biochemical, and pathological study of perinatal lambs in a commercial low ground flock in the Scottish borders with a history of substantial perinatal mortality revealed that placental insufficiency was involved in 24% of deaths, acute hypoxemia at birth in 35%, inadequate thermogenesis in 12%, and starvation in 12%. With only clinicopathological criteria, 37% of the lamb deaths were attributed to antenatal influences, which included immaturity, developmental anomalies, and degenerative or inflammatory changes; 33% of the deaths were the result of postnatal factors, which included (in declining order of frequency) starvation, enteritis, misadventure, pneumonia, navel infections, and septicemia (Barlow et al, 1987). No conclusions could be made from the pathological examinations alone in the remaining 30%, although almost half of these had low rectal temperatures after birth, with death being attributed to hypothermia. It is emphasized that antenatal influences can cause weaknesses in lambs that may lead to deaths, only a proportion of which are accompanied by morphological changes. These data highlight the importance of correct nutrition throughout pregnancy; unfortunately, detailed monitoring of flock nutrition during late gestation was not undertaken in this study (Barlow et al, 1987). Perinatal lamb losses as low as 3% can be achieved in well-managed flocks, indicating that the antenatal factors described above can be resolved by correct nutrition and management practices.

Causes of Perinatal Mortality

Classification

On any sheep farm, there are losses of lambs in utero, because of prolonged second stage labor, and in the neonatal period. When recommending a health management program to limit these losses, the veterinarian must know the important modes of loss on the particular farm. In sheep flocks it is common to find that more than one cause—and often a number of causes—contribute significantly to the total loss (Fig. 16-4).

Determination of the exact cause or causes of loss is usually difficult because the principal requirements—to observe closely, record carefully, and classify accurately—are not easy in the sheep-farming environment. A system of classification is illustrated in Fig. 16-5 based on an overall group of perinatal mortality (Dennis, 1972b) that included all deaths from late pregnancy to 28 days after parturition. The categories of the times of death are shown in Box 16-10.

Diagnosis of Specific Causes

On the basis of the history of the mortality and the gross changes at necropsy examination, it should be possible to categorize the cause as being either environmental or deriving from the characteristics of the lamb or ewe.

Environmental Factors. These include climate (inclement cold or hot weather), nutritional inadequacies or deficiencies (general inanition, iodine—goiter, copper—swayback, selenium-vitamin E—white muscle disease), predators, and infections (congenital or extrauterine, with or without immune deficiency).

Ewe Characteristics. These include breed, age, mothering capability and milk production, and dystocia.

Lamb Characteristics. These include lamb size (dystocia, undersized and weak), litter size, malpresentation, malposture, malposition, congenital defects, and lack of vigor (many causes).

Evaluation of Perinatal Mortality

A high perinatal death loss may be obvious, with a large number of dead lambs. In other extensive circumstances, it

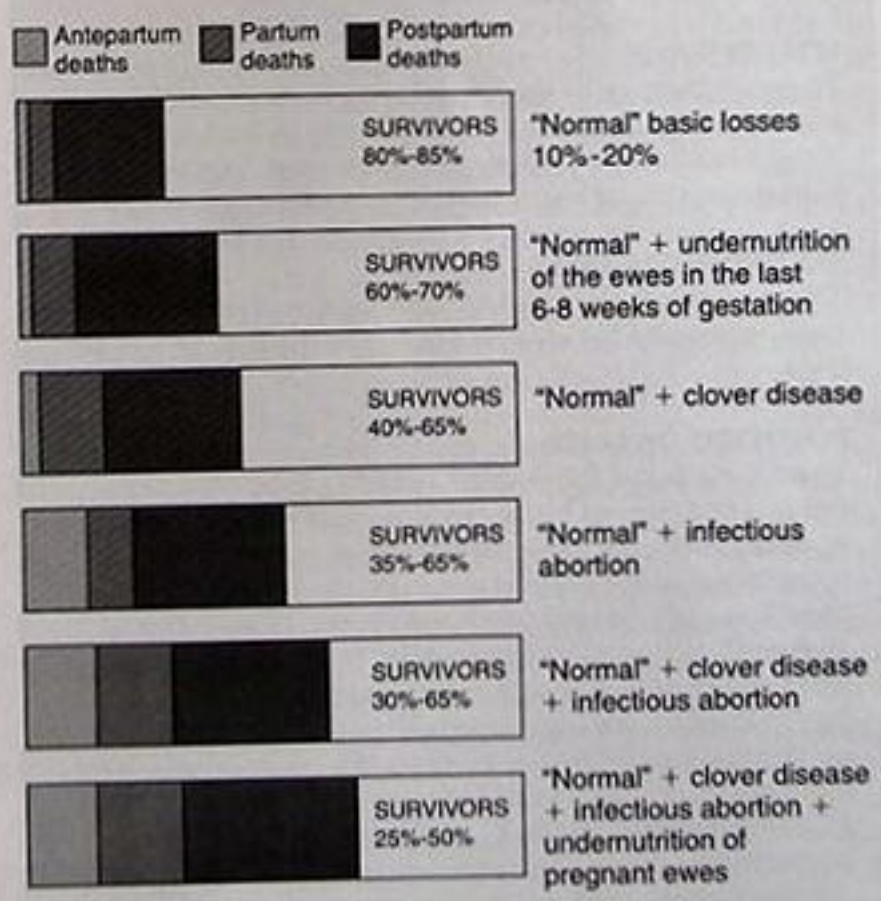

FIG. 16-4 Causes of perinatal lamb losses. (From Dennis SM: *Cornell Vet* 62:253-262, 1972.)

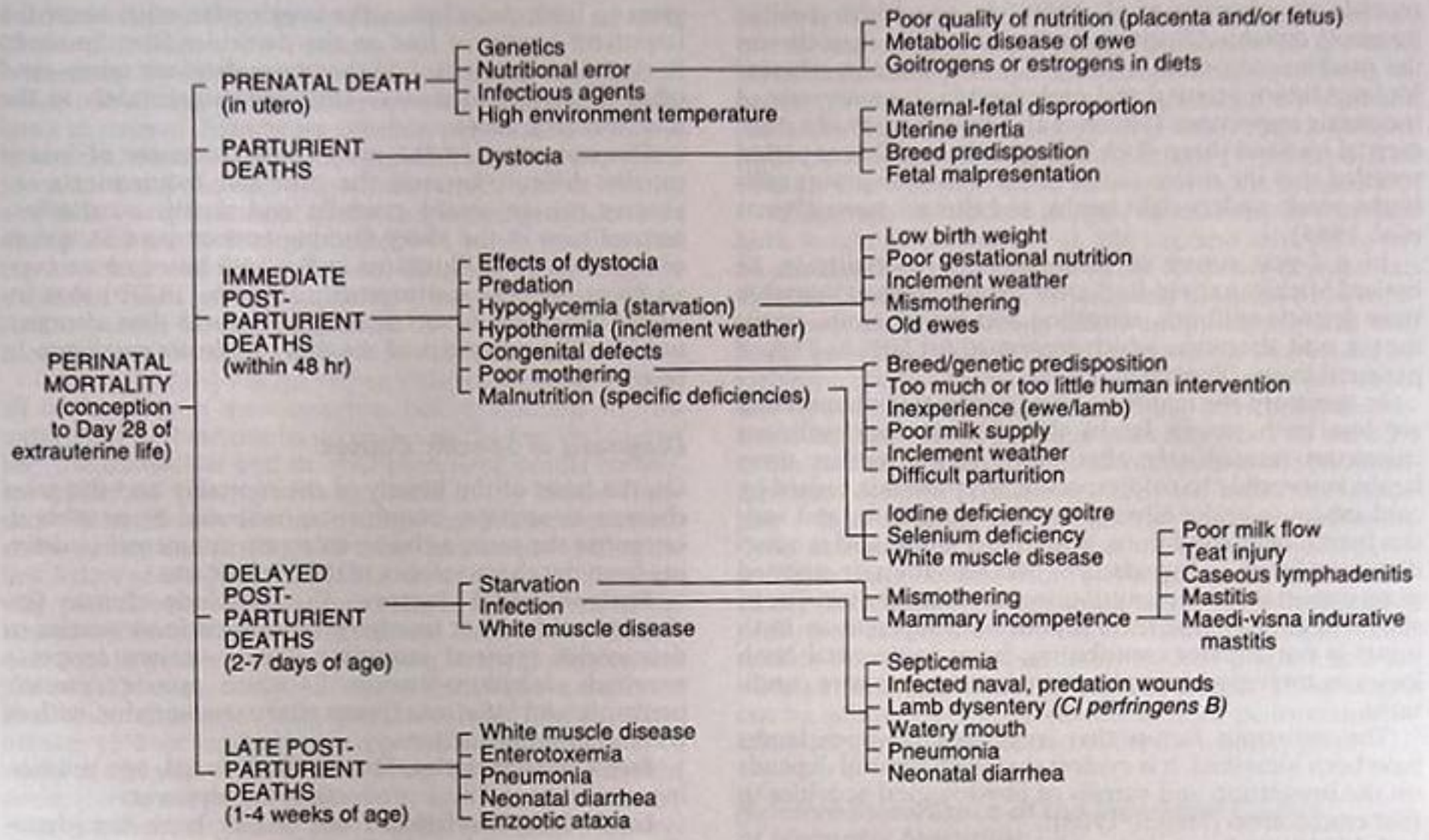

FIG. 16-5 Classification of perinatal deaths of lambs.

BOX 16-10

Categories of the Times of Death

FETAL DISEASES
These are diseases of the fetus during intrauterine life, such as prolonged gestation, congenital defects, infectious disease including toxoplasmosis, abortion, fetal death with resorption or mummification, and goitre.

PARTURIENT DISEASES
These are metabolic diseases associated with dystocia causing cerebral hypoxia and injury to the skeleton or soft tissues.

POSTNATAL DISEASES
These include the following: (1) early postnatal disease (within 48 hours of birth), such as malnutrition because of poor mothering, hypothermia from cold exposure, and infectious diseases such as omphalophlebitis and colibacillosis, (2) delayed postnatal disease (2 to 7 days of age), such as desertion by the dam; mammary incompetence resulting in starvation; increased susceptibility to bacterial infections including colibacillosis, meningitis, peritonitis, hepatic necrobacillosis, and polyarthritis; and lamb dysentery because of hypogammaglobulinemia, and (3) late postnatal disease (1 to 4 weeks of age), such as white muscle disease and enterotoxemia.

Failure to establish pregnancy, early embryonic death, and abortion are presented in the chapter.

may only become apparent as a high level of positive pregnancy diagnoses followed by a low lamb-marking percentage. Perinatal lamb losses are therefore often much greater than farmers realize, and the first objective is to determine the extent of the problem. This section on techniques is recommended as a guide to examining a problem in a flock (Plant, 1977) or to developing a monitoring system to include in a continuing flock health program.

As a general rule, under extensive conditions, it is recommended that losses of less than 15% of all lambs, or less than 10% of ewes losing all their lambs, are within the bounds of normality and are not economical to investigate in detail. It is unlikely that a cost-effective program could be mounted against the causes in these flocks. Under intensive and housed conditions, the perinatal mortality rate should not exceed about 5%, but few flocks ever achieve that level of performance (MLC Yearbook, 1997).

Analysis of Retrospective Data. Careful examination of past lambing records should be combined with a description of the management of the farm and its physical resources. This analysis can pay excellent dividends if there are good records. It provides an assessment of the size of the problem and indicates which phase of the lambing sequence is the location of the error. Suitable areas for analysis are shown in Box 16-11.

A simple system for recording the events associated with each lamb death in commercial flocks is shown in Fig. 16-6 (Eales et al, 1986b). This information is recorded for each lamb and then collated, summarized, and assessed, together with the clinical and necropsy data. The results can reveal the extent of lamb losses and provide an indication of the areas of management requiring improvement.

BOX 16-11

Analysis of Retrospective Data

Time of day, season, prevailing weather at lambing, reasons for timing
Geographic location of lambing paddocks or areas, shelter available
Size of ewe flocks, degree and frequency of supervision
Supplementary feeding during late pregnancy
Number of ewes requiring assistance at lambing
Quality of predator control
Tranquility of ewe flock under supervision
Use of pens for confining ewes and lambs
Vaccination program
Immediate postpartum care of ewes and lambs, including preventive treatments
Length of lambing season
Lambing percentage. Method of estimation should be as follows (ensure that nonpregnant ewes are included):

$$\frac{\text{Lambs born}}{\text{Ewes put to ram}} \times 100$$

Stillbirth rate and abortion rate (many causes of infectious abortion can result in stillbirths and weak lambs)
Losses at marking
Losses at weaning
Weaning policy, age, weight, amount of feed available

Special Examination of Flock to Decide Reproductive Efficiency at Lambing. The two recommended examinations are those for pregnancy diagnosis and those ewes not nursing lambs.

Observation of Flocks at Lambing. Differentiation between mismothering by ewes and lack of vigor in lambs as causes of death by starvation of lambs is important, but it can only be studied by the farmer through several observations of the flock during the day. Starvation from death or absence of the ewe or because of failure of lactation is usually clear-cut. The lambs, although still alive, are dejected, hunched up, gaunt, and hungry. In the United Kingdom demonstration of the empty abomasum by ultrasonography in lambs suffering from starvation has reinforced this problem area to farmers and shepherds in the lambing shed (Scott et al, 1997) without the need to undertake necropsies or laboratory measures to determine passive antibody transfer. Eventually, lambs suffering from starvation become comatose and hypothermic. Necropsy findings are confined to dehydration, loss of brown fat stores, and serous atrophy. Absence of perirenal and epicardial groove fat is indicative of starvation. Be aware that there may be milk in the abomasum if the lamb has been fed recently by esophageal feeder, but this milk will not have clotted and the remainder of the lower intestinal tract is empty.

When the cause of starvation is lack of vigor of the lamb, the signs and lesions of starvation are complicated by those of the primary cause, which may be infection (Scott and Gessert, 1996,b), dystocia, low birth weight, poor body fat stores, exposure to cold or heat, and congenital defects. They are accordingly more difficult to identify, and the only satisfactory way of identifying specific causes in lambs' dying of starvation is methodical observation and examination of the flock. When the cause of lack of vigor in lambs is undernutrition while in utero, it is necessary to identify this on the basis of low body weight at birth and an absence of placental lesions. The history of availability of feed and evidence of low BCS in the ewes is confirmatory evidence.

An accurate count of dead lambs is the only way to determine how many lambs have been lost. Ewes with twins may lose one and may not be noticed readily.

When a large number of lambs are dying over a short period, it requires some thought to devise a system of carrying out necropsy examinations in order to obtain significant results without prohibitive cost. First, it is necessary to conduct examinations to determine whether the lamb died of dystocia, hypothermia, starvation, predation, infection, or a new category that requires investigation. In other words, did the lamb die of a specific cause related to a proposed or existing control measure? Having categorized the death, it may be necessary to pursue a "new category" series of deaths to a more definite end. It is even more necessary, though, to examine a predetermined number of dead lambs to obtain a statistically meaningful result. This is not only a matter of numbers but a matter of selecting postmortem specimens in a random manner. It is easy to get a biased sample if it is left to the farmer to pick up the lambs selected for postmortem examination. If possible, the placentae should also be collected, because it is a better sample for evaluating for an infectious agent. When the farmer is bringing the lambs in, it is usually possible to have all of one day's pickup put into a waterproof bag and to bring the dated bags every third day. The bags must carry the date of pickup, information on weather, and so on.

A technique for a standardized postmortem examination has been described by McFarlane (1965, 1966) and is in general use. Its purpose is to establish whether the death was preparturient, parturient, or postparturient, and whether postparturient death was soon or late after birth.

The system depends on a number of critical "lesions" that suggest that particular lambs should be classified into one of 21 time categories relative to parturition. Thus lambs that have died intrauterine (e.g., preparturient deaths) show rapid autolysis of the subcapsular renal cortex. Postmortem discoloration and mummification occur at further time intervals. Parturient deaths are indicated by local edema of parts of the body jammed within the pelvis, in which circulation has been constricted; the lungs are aerated, and there is often hemorrhage from the liver. Postparturient deaths are divided into immediate, delayed, and late categories, and classification is made on the basis of aeration of lungs, the state of the umbilical artery, the degree of mobilization of body fat, the soles of the feet as an indication of whether the lamb has walked, and the presence of ingesta along the length of the gut. These findings are shown in Table 16-5. Severe cases of goiter are readily recognized at necropsy, but weighing the thyroid glands may be necessary to make a diagnosis in flocks in which hypothyroidism is suspected of being a contributory rather than a principal cause (Setchell et al, 1960).

Head Count of Ewes and Lambs at Marking (Docking). This provides an opportunity to segregate the lactating ewes from the ones that have not lambed. Ewes that have lambed, but have lost all their lambs, have enlarged udders containing secretions of various kinds, depending on when the lambs ceased to suck. Ewes that have not lambed have small, empty udders and no staining of the perineal wool. Detection of these ewes is greatly helped by a previous pregnancy diagnosis.

The valuable information that should be gained from a marking count includes marking percentage (e.g., of ewes bred), percentage of lambs to ewes present (the twinning index), and lambed ewes that have no lamb (loss of lambs from various causes).

Date: _____

Weather: Good/Indifferent/Bad

Housing: In/Out Claiming pens: Yes/No

EWE: Age: ____ Condition score: _____

Disease: _____

LAMBS: Litter size: 1/2/3/4

Age at death(hr) 0, 0–5, 5–12, 12–24, 24–48, 48+

Weight: _____ kg Birth problem: Yes/No

Abortion: Yes/No

Stillbirth: Decomposed: Yes/No

Swelling of head or limb: Yes/No

Postnatal death: _____

Temperature: _____

Diarrhea: Yes/No

Watery mouth: Yes/No

Lame: Yes/No

Swollen joint: Yes/No

Stomach: Full/Empty

Other: _____

_____

FIG. 16-6 Record of events related to lamb deaths in commercial flocks. (Adapted from Eales FA, Small J, Gilmour JS: *Vet Rec* 118:227-230, 1986.)

Specific Environmental Causes of Lamb Deaths

Inclement Weather

Cold exposure resulting in hypothermia is a primary cause of lamb mortality when large numbers of lambs die during or soon after periods of low temperatures (lower than 5° C [41° F]) with wind and rain. The high mortality rates in newborn lambs resulting from the effects of cold exposure and starvation occur because many of these lambs are born during the late winter and early spring, when adverse conditions are most likely to occur. This is particularly true in the northern United States, Canada, and the United Kingdom (Eales and Small, 1986). Lambs are often born outdoors in unprotected pens designed to accommodate large numbers of ewes. Cold stressed lambs often become hypothermic because of excessive heat loss from exposure to inclement weather and poor heat production caused by either hypoxia during the birth process or starvation. Factors that further increase the susceptibility of lambs to hypothermia include poor mothering instincts of the dam; lambs from ewes in poor condition, from young or aged ewes, from multiple births, or from dystocias; and those with small birth weight and born prematurely. Breed differences, length of birth coat, wetting of the birth coat, and exposure to wind are additional factors that influence the susceptibility of newborn lambs to cold exposure. Cold-induced changes in lambs include physical weakness, depression, and poor nursing re-

TABLE 16-5

Guide to Determination of Time of Lamb Death Based on Postmortem Examination

Stage	Blood-Stained Subcutaneous Edema	Breakdown of Fetal Tissues	Renal Autolysis	Thrombosis of Umbilical Artery*	Aeration of Lungs†	Soles of Feet Worn‡	Ingesta in Gut§	Body Fat State‖
Acute parturient	Generalized extensive	Mummification	Marked	—	—	—	—	Autolyzed
Parturient	Local to presented parts	—	Slight or nil	—	±	—	—	Stable
Immediate postparturient	—	—	—	±	+	±	—	Stable
Delayed postparturient	—	—	—	±	+	+	±	Stable
Late postparturient	—	—	—	+	+	+	+	Marked catabolism

*Thrombosis of umbilical artery indicates that lamb has survived birth process.
†Aerated state of lungs indicates that lamb has breathed.
‡Wear on soft sole of foot indicates that lamb has walked.
§Milk in the intestine and milk fat in the lymphatics of the gut indicate that the lamb has sucked.
‖Catabolism of the body fat (not white as normal, but yellow-brown gelatinous material) indicates lamb has mobilized fat to convert energy and suggests that nutritional stress has occurred.

sponse. The mortality rate was 40% in cold-stressed lambs and 10% in lambs kept at warmer temperatures (Olson et al, 1987).

Experimentally, wetness is the single most important factor determining whether lambs become hypothermic (McCutcheon et al, 1983a,b). Wet lambs suffer a reduction in coat insulation, primarily as a result of reduced coat depth, but this effect is small compared with the increase in evaporative heat loss that occurs as a result of wetting (McCutcheon et al, 1983a,b). Lambs exposed to experimental air movement from a fan produced more body heat than those in still air, and differences in resistance to cold stress between single and twin lambs were largely caused by the corresponding differences in body weight and coat depth.

In newborn lambs, as in piglets and infants, carbohydrate and lipids are the major energy substrates for heat production because protein catabolism is minimal during the first day after birth (Mellor and Cockburn, 1986). Liver glycogen concentrations increase markedly during the last few days before normal parturition. The amount of liver and skeletal muscle glycogen available in the newborn lamb at birth determines how long it can avoid hypoglycemia and hypothermia if not fed. The amount of lipid present in the newborn lamb can also affect the duration of the glycogen reserves. In growth-retarded lambs—either the result of poor placental function or inadequate late gestation dam nutrition—lipid availability is decreased and glycogen exhaustion occurs earlier than normal. Such lambs are highly susceptible to hypothermia that can be minimized by the early ingestion of colostrum, which is rich in lipid and extends the availability of glycogen.

Deaths from cold exposure are the result of excessive body cooling because of low temperatures, driving winds, and starvation. The starvation results indirectly either from poor mothering by the ewe or because the lamb is weak as a result of poor antepartum nutrition. At necropsy, the findings are not remarkable but are diagnostic. The lambs may have sucked, but there is little digestion, and the intestine on the recumbent side is flaccid. There are also subcutaneous hemorrhages of the limbs and depletion of brown fat stores. The weather history preceding the deaths is an important indicator.

The relative importance of environmental and maternal factors with regard to neonatal mortality is not easy to determine. The preponderance of evidence supports the view that inclement weather kills many lambs, probably more than would otherwise die. Those lambs that are susceptible have reduced vigor resulting from either poor preceding nutrition or poor mothering ability of the dam (Alexander and Peterson, 1961; Alexander 1962, 1964; Alexander et al, 1979). The vigor of the lamb, principally manifested as "sucking drive," is reduced by lack of reward, so that a vicious cycle is created if the ewe does not stand. Vigor is also greatly reduced by cold discomfort, giving inclement weather two points at which it influences lamb survival rates (Alexander and Williams, 1966). The lamb dies of hypothermia and inanition.

Nutritional Inadequacies

General Inanition. A total lack of colostrum and milk intake most commonly results because of inadequate nutrition of the pregnant ewe, but other factors including severe weather, too much human intervention at lambing time in nervous ewes, or lack of vigor of the lamb may be variably involved. Normal lambs are born with sufficient nutritional reserves to last for 1 to 4 days, so that deaths from starvation occur after this period. The starvation may be primary or secondary. Primary starvation results from absence of the

milk supply. Secondary starvation occurs when the lamb lacks sucking vigor because of another primary cause, including mismothering by the ewe, damage to the teats or udder (Hayman et al, 1955), and poor nutrition of the ewe (Bareham, 1976). Some aspects of poor mothering can be overcome by confining ewes and her lamb(s) in individual pens, which are widely used in North America and the United Kingdom.

The nutrition of the ewe, inasmuch as it determines her body condition and milk flow, has a considerable effect on her mothering tendency and energy supply to the lamb.

Another way in which nutrition of the ewe exerts its influence on lamb survival is through improved nutrition of the fetal lamb and its greater size and strength at birth (Khalaf et al, 1979). Overfeeding can also be harmful in that lambs are overweight and may develop dystocia, but this situation is unusual in prolific flocks. The widespread use of ultrasonography to determine fetal number during midgestation has resulted in more appropriate nutrition during late gestation, and absolute fetal oversize is an uncommon problem in most flocks. As a general guide, it is recommended that ewes should maintain their own body condition in late pregnancy and at the same time gain 15 to 20 lb in the 6 weeks before lambing. More accurate feeding strategies have been described (Russel, 1985) based on certain blood metabolites.

Later on in the lamb's life, nutrition of the ewe exerts still another effect. High-plane nutrition of the ewe leads to a high milk yield and the maintenance of a strong ewe-lamb bond. Ewes on a low plane of nutrition tend to reach the threshold milk yield, which leads to voluntary weaning much earlier. The growth rate of lambs and even their survival may be affected at this point (Arnold et al, 1978).

Specific Nutritional Deficiencies. Common deficiencies include iodine-deficient goitre, nutritional muscular dystrophy caused by selenium and vitamin E deficiencies, and congenital swayback and enzootic ataxia, caused by copper deficiency. White muscle disease can develop in utero (Hamliri et al, 1990). Cobalt deficiency in ewes may influence the growth rate of their lambs (Quirk and Norton, 1987; Fisher, 1990). Outbreaks of hypocalcemia can occur in late pregnant ewes that are fed a diet deficient in calcium and energy (Sweeney and Cudderford, 1987).

Orally Ingested Poisons

Plant poisons include *Veratrum californicum*, which causes brain defects and prolonged gestation, and *Astragalus* and *Oxytropis* sp., which cause limb contractures. *Brassica* sp. can be goitrogenic.

Infectious Diseases Causing Neonatal Lamb Mortality

Infectious diseases causing lamb mortality can be the result of congenitally acquired infections, such as *T. gondii*, *Chlamydia psittaci*, border disease virus, and *Listeria monocytogenes*. The bluetongue virus can cause hydranencephaly, prolonged gestation, and stillborn or weak lambs.

Postnatal infections include those found in Box 16-12.

In sheep, much more so than in cattle, the infections that cause abortion also cause fetal and neonatal deaths. They are more accurately identified as fetal-neonatal syndromes (Dennis, 1972b; Hartley, 1968).

The prevalence of neonatal infections varies. In New Zealand, up to 30% of total deaths, and in Scotland (Watt, 1980) 18% of total deaths, are attributed to infectious disease. Remember, however, that many shepherds in the United Kingdom routinely administer an oral antibiotic to lambs within the first 15 minutes of life to prevent watery mouth disease, as recommended (Eales et al, 1985). In Australia, a similar level of such infections—up to 30% of total lamb deaths—has been reported (Hartley and Boyes, 1964; Hughes et al, 1964; Haughey et al, 1967). In general, the tendency is to make little of the role of neonatal infections in causing lamb mortalities, because the mortality rate in flocks caused by these infections is often as low as 1%. This happens often, especially in merino flocks; more obvious reasons for lamb mortalities, such as deleterious climate and nutrition, are usually readily available.

Laboratory culture of every lamb in an investigation is neither possible nor advised. The recommended alternative is to culture from those carcasses that show lesions suggestive of congenital infection. These include subcutaneous tissue, usually blood-tinged, excess fluid and fibrin in body cavities, hepatomegaly, focal hepatic lesions, intestinal hyperemia, enlarged mesenteric lymph nodes, and bright yellow meconium.

The incidence of late postparturient deaths (1 to 4 weeks of age) in lambs is usually low, about 1.6% of all dead lambs (Hughes et al, 1971). In terms of late postparturient deaths, the infections represented only 3.3%. A much higher incidence is frequently reported, and the result largely depends on local conditions and the size of the sample. The infections recorded include the common pathogens of *Chlamydia*, *P. haemolytica*, *Fusobacterium necrophorum*, and *Clostridium* sp., but without emphasis on any particular agent. *B. ovis* has been identified as causing abortion in some sheep flocks and is suspected as a cause of perinatal lamb deaths through congenital infections in others (Haughey et al, 1968). Tetanus is one of the more common infections but is much less common now when routine vaccination is used. In lambs at pasture, especially under intensive management systems on lush pasture or creep grain-fed lambs, enterotoxemia caused by *C. perfringens* type D (pulpy kidney) may occur in outbreak form and routine vaccination of ewes before lambing is essential. When outbreaks of the disease occur in unvaccinated grain-fed lambs, the administration

BOX 16-12

Postnatal Infections

Septicemias: *Escherichia coli*, *Listeria monocytogenes*, *Salmonella* sp., *Pasteurella haemolytica*
Bacteremias with localization in joints, endocardium, and eyes caused by streptococci, especially *Streptococcus dysgalactiae*,* staphylococci, *Erysipelothrix rhusiopathiae*
Navel infections with a mixed bacterial flora
Diarrhea with dehydration: colibacillosis, rotavirus infection, and *Cryptosporidia parvum*
Pneumonia caused by *P. haemolytica*
Toxemias: gas gangrene of the navel, crow-picked eye† caused by *Clostridium septicum* or *Clostridium oedematiens*, lamb dysentery caused by *Clostridium perfringens* type B
Watery mouth disease‡ commonly associated with *E. coli* endotoxemia

*Watkins GH, Sharp MW: *Vet J* 155:235-238, 1998.
†Smith ID: *Aust Vet J* 47:333-335, 1965.
‡ Gilmour JS, Donachie W, Eales FA: *Vet Rec* 117:335-337, 1985; Eales FA, Small J, Gilmour JS, et al: *Vet Rec* 119:543-547, 1986; Scott and Gessert: *Vet Rec* 139:117-118, 1996.

of antitoxin may be indicated along with removal from grain for several days. Contagious ecthyma (Orf, contagious pustular dermatitis) may occur in unweaned lambs, especially when they are artificially reared. Vaccination provides variable protection and may cause widespread dissemination of the live virus, thereby worsening the situation.

Necropsy lesions that suggest postnatal infection are omphaloperitonitis; focal suppurative lesions in any solid viscera or skeleton; and pneumonia, arthritis, and enteritis. The specific infection with *C. perfringens* type B (lamb dysentery) characterized by a hemorrhagic enteritis is now uncommon because of routine vaccination. Clostridial infections of navels, predator-inflicted wounds, and docking wounds are also uncommon because of the awareness by farmers of the need for hygiene or prophylactic treatment at these times.

The clinical picture associated with neonatal infections, whether prenatal or postnatal, is likely to include a range of septicemia with sudden death or navel-ill accompanied by one or all of the following: meningitis, arthritis, endocarditis, and panophthalmitis. The most common is arthritis, either suppurative and caused by streptococcal or staphylococcal infections, or nonsuppurative and caused by *Erysipelothrix insidiosa*. These diseases are amenable to early and aggressive antibiotic treatment, but the prognosis is guarded if the condition has not been detected for 2 or more days. Hygiene at lambing to avoid umbilical infection and sterilization of instruments at tail docking and castration are appropriate preventive measures but rarely eliminate the problem. Recent studies (Watkins and Sharp, 1998) question whether the umbilicus is the primary portal of entry for *Streptococcus dysgalactiae* whereby only 16% of lambs with arthritis had omphalitis. Similarly, in lambs with meningitis the umbilicus was considered an unlikely portal of infection (Scott et al, 1994).

As in other species, there is a relationship among poor husbandry, failure of passive antibody transfer, and a high level of neonatal infection (Ducker and Fraser, 1973). Poor mothering by the ewe or interference with mothering by too much human intervention can predispose to neonatal infection by delaying passive antibody transfer.

Blowfly strike of navels or castration wounds can occur but are uncommon, because it is not usual to perform these operations during a dangerous period. In merinos it is a more common practice to carry out the Mules operation when docking and castrating, and the usual recommendations about hygiene to prevent infection through these wounds should be instituted. The welfare implications of this mutilation require urgent review.

Predation

Predatory birds and animals are responsible for much postmortem mutilation of carcasses and for some deaths of lambs weakened by other influences. Under extensive conditions, a wide range of animals and birds, including eagles, ravens, foxes, and feral pigs, are considered to cause significant losses (Smith, 1965a). In Australia, crows are a significant cause of loss, but their significance is much less than that of foxes; feral pigs are the worst of all, being capable of killing 80% of lambs born (Plant et al, 1978). In the United States (Dennis, 1980; Green and Woodruff, 1983/1984), more than 8% of all lambs born may die because of predation. Most deaths are caused by coyotes, which are credited with 93% of losses. The methods used for predator control included electric fencing, housing in barn at night, hunt predators, and guard dogs. The use of guard dogs to protect sheep from coyotes has been effective (Green and Woodruff, 1983/1984).

Determination that predatory injuries have occurred antemortem depends on the presence of hemorrhage in the region of the injury. Tissue disruption and broken bones may occur antemortem or postmortem. There may be mutilation, but hemorrhage is not present when the damage occurs after death. Deaths in this group should be classified as predation killing of a healthy animal or mutilation by a scavenger when the subject is ill or dead when first attacked.

Some information about the identity of the predator may be deduced from an inspection of the cadaver. Foxes and coyotes bite the neck, head, and face of lambs, causing extensive hemorrhage in the area and often crushing or tearing open the larynx. Death occurs as a result of suffocation or hemorrhage. Fang marks through the skin are accompanied by teeth marks, often more visible on the inside of the skin. Coyotes may eat part of the carcass, a hind leg of an older lamb, or the internal organs, heart, liver, and abomasum full of the milk of newborn lambs. Foxes favor the tongue, lower jaw, tail, and thigh. Dogs, which usually hunt in pairs, do not kill for food, and many lambs or sheep may be killed or mortally wounded in one attack. There are usually many bites anywhere on the body. Older sheep are torn about the flanks and thighs. Lambs are often crushed and the limbs stripped of flesh. Crows are poorly equipped to predate and are restricted to gaining access to the interior through the natural opening of an animal already attacked by another predator or already ill from another disease. Common targets are the tongue, eyes, anus, and umbilicus. Eagles and other avian predators and scavengers have the same predilection for tongues and eyes. Eagles usually leave talon marks along the back of a predated lamb.

Specific Ewe Causes

Breed of Sheep

The breed of sheep has an effect on the survival rate of lambs (Wiener et al, 1983). There are also apparent differences among families. The differences among strains of sheep within a breed, however, have not been shown to be significant (Lax and Turner, 1965; Arnold and Morgan, 1975). Among breeds, merinos are notoriously poor mothers, especially young ewes. Desertion of lambs at birth is common, and the lambs die of starvation. There is a great deal of difference in mothering traits among ewes, and ewes that are poor mothers often respond poorly to intensive lambing techniques (Hancock, 1996). Selection of the breed of sheep also determines the rate of twinning, and, because twins are much more sensitive to environmental insults in early life than singles, they are likely to have a much higher mortality rate. Selection for twinning, especially in merinos, should not be attempted unless intensive lambing facilities are available. The lower average birth rate of twins probably contributes to this higher mortality rate. Certainly, high- and low-weight singles have less chance of survival than those in the median zone (Purser and Young, 1964). The breeds of sheep that are good mothers include the Scottish Blackface, Charollais, Texel, Dorsets, Arcotts, Finnsheep, and Polyday and hybrid ewes.

Age of Ewe

There is a significantly higher survival rate in lambs from middle-aged merino ewes than those from either 2- or 7-year-old merino ewes. In part, this is the result of the better milk supply and mothering instincts of the middle-aged ewe, but there are other factors, such as the higher birth weights of the lambs, that favor the lamb of the middle-aged ewe. Deaths in lambs from young ewes is likely to be caused by dystocia, whereas in old ewes, death is more likely to be from starvation. Similar findings have been recorded for Norwegian sheep (Lutnaes, 1982).

Dystocia

The literature on the causes of dystocia in sheep is sparse and somewhat contradictory. Some early studies indicated that most cases of dystocia in ewes are caused by absolute fetal oversize exacerbated by overnutrition, but it was also considered genetically disposed by the presence of large heads, as in Dorset Horns, Southdowns (Dennis, 1970), and Romneys (Hartley and Kater, 1964). Some studies have indicated that the proportion of dystocias is 70% in Southdowns, 28% in Marshall Romneys, and as low as 4% in fine-wooled merinos (George, 1975). Correspondingly, the percentage of neonatal deaths that result from dystocia is lower (10% of all neonatal mortality) in merinos than for crossbreds (10% to 34%) and Dorset Horns (36%) (George, 1976). A recent study (Safir, 1991) reported only 0.5% of lamb losses attributable to dystocia in a flock with continuous supervision.

A large-scale farm-based survey by Gunn (1968) revealed an overall incidence of dystocia of 3.1% in 15,584 ewes from Scottish hill flocks. In that survey, 65% of assisted births involved postural abnormalities of the lambs, of which 42% involved the head only, 29% the head and one leg, 17% breech presentation, and 6% the forelegs only. Ellis (1958) reported similar results. In a survey of the causes of dystocia in sheep in western Wales, incomplete dilatation of the cervix (ring womb) was the most common primary cause, accounting for 26.8% of cases (Thomas, 1990). In this survey, ring womb had no breed, age, or condition score predisposition, but it was associated with a higher lambing percentage (ewes with ring womb produced 1.94 lambs/birth compared with the overall average of 1.67 lambs/birth). Many of the cases of ring womb were associated with simultaneous presentation of more than one lamb, thus altering the distribution of pressure on the cervix and probably influencing dilatation. Postural abnormalities (head deviation, flexed foreleg posture, breech presentation, and flexed hock posture) accounted for a total of 34.5% of the cases of dystocia. Fetomaternal disproportion accounted for only 3.0% of the dystocia cases, and the average BCS of the ewes with this dystocia was 3.4 compared with the overall average of 2.7. All cases of fetomaternal disproportion involved the birth of single lambs, with a significantly greater number in primiparous ewes. Fetomaternal disproportion was concluded to be essentially a management problem resulting from improper ram selection, especially with regard to primiparous ewes (Thomas, 1990).

The factors contributing to improved lamb survival in Marshall Romney sheep were identified and quantified over a period of 3 years in a flock of Marshall Romneys compared with a control flock of Romney sheep (Knight et al, 1988). The aim of the experiment was to identify major differences in the causes of lamb mortality and to determine the contributions of lamb birth weight and shape, ewe behavior, pelvic area, ram and ewe hemoglobin type, and gestation length to the differences in lamb survival (Knight et al, 1988). Marshall Romney ewes have been selected for many years for their ability to survive, to lamb unassisted, and to rear lambs with minimal shepherding under hard hill conditions (Knight et al, 1988). The factors that contributed to an increased survival rate in Marshall Romney sheep included a lower incidence of periparturient deaths from dystocia, of deaths from infections, and of starvation (Knight et al, 1988). The increased lamb survival in a Marshall Romney flock can result from contributions from both the ewe and the ram. More Marshall Romney ewes rear a lamb and more twin-bearing Marshall Romney ewes rear both lambs compared with control Romney ewes (Knight et al, 1988). The improved survival was also the result of a greater maternal pelvic opening and better maternal behavior in Marshall Romney sheep than the Romney breed. The optimum birth weight for survival was 4.6 kg, but skeletal size and shape influenced lamb survival independently of birth weight. The Marshall Romney ewes selected more sheltered lambing sites and had a stronger maternal bond, which was indicated by their response to the shepherd during tagging of the lambs. Ewes that stayed close to their lambs while they were tagged had a higher lamb survival, which is similar to observations in other genotypes.

In the long term, the positive approach to reducing the losses caused by dystocia depends on genetic selection against small pelvic diameters and large lambs or lamb heads. These criteria have been used effectively in a culling program to reduce greatly the occurrence of dystocia in Romney Marsh sheep (McSporran et al, 1977). In Dorset Horns (Fogarty and Thompson, 1974) a close relationship between pelvic size and dystocia has been observed, and in Australia a relationship between fetal size and dystocia has been observed in fine-wooled merinos and Cheviots (Whitelaw and Watchorn, 1975; Smith, 1977). If the pelvis is measured as an aid to selection, it is the internal measurement that is of importance; the external measurement is not a reliable guide (McSporran et al, 1979). However, the size of the fetus is also important, and there is little value in predicting the ease of lambing using only maternal pelvic size (Silva and Noakes, 1984). Death is usually the result of asphyxia, but this may also occur in births of long duration without obvious obstructions. Severe hypoxia during birth leads to a metabolic acidosis and depressed heat production capacity (Eales and Small, 1985). Occasionally, death is caused by rupture of the liver (Johnston and McLachlan, 1986).

Lambs dead of dystocia are characterized by localized edema of the head, tongue, and forelimbs in anterior presentations and of the perineum and tail in posterior or breech presentations (Hartley and Kater, 1964; Wilsmore, 1989). Lambs that survive a difficult birth may die subsequently of starvation because of poor mothering by the ewe. Others may die of injury incurred during parturition, including intracranial hemorrhage (Haughey, 1973). The injury to the central nervous system appears to be the critical factor rather than an indirect effect on food intake (Duff et al, 1982).

Mothering Capability

The mothering ability of the ewe, especially under breeds of sheep, has been discussed earlier. There are some other management points. Lambs are not discriminatory and suck any ewe. However, ewes are discriminatory and vary in their selectivity. Some ewes before lambing are receptive and actually search out and steal lambs from other ewes. Others are antagonistic to their lambs and desert them readily. This mothering trait may be innate and inherited. It may be interfered with by managerial factors such as too much human interference, prolonged parturition including dystocia, poor milk supply, and poor vigor of the lamb. The teat-seeking activities of lambs are subject to the same sorts of influences and may be absent or weak at birth. In normal lambs, there is a high level of teat-seeking activity at birth, but this declines rapidly to about 10% at 12 hours of age. It declines when the lamb is starved and when the weather is cold and the lamb is hypothermic, especially in the first few hours of life. Maternal behavior is likely to be interfered with by flocking behavior, in which the ewe tends to move to the rest of the flock rather than to her lamb. This tendency is likely to increase as the lamb gets older.

Udder Health, Milk Production, and Mastitis

At weaning and at birth, the udders of ewes should be examined to ensure that both glands are functional and the teat canals are patent. Significant losses can occur in ewes with teats damaged during shearing and glands destroyed by *Corynebacterium pseudotuberculosis* (Hayman et al, 1955), and in ewes with fibrosed udders (Kirk et al, 1980).

Mastitis is an economically important disease for sheep producers because of premature culling of ewes with udder abnormalities and of reduced growth rate and survival of lambs nursing ewes with mastitis (Hueston et al, 1989). The prevalence of defective udders may be as high as 12% in abattoir surveys of cull ewes (Madel, 1981) but the udder-teat lesions may have been the reason for premature culling. The most important variable affecting lamb growth is the milk yield of the ewe; the variation in milk yield can account for 56% of the variation in lamb growth rate (Jordan and Mayer, 1989). Surveys of ewes from 4 to 6 weeks after lambing revealed a prevalence of intramammary infection of 14% of ewes and 8% of glands (Watson et al, 1990). The prevalence is positively correlated with age; 2- and 6-year-old ewes had, respectively, 4.4% and 14.0% of glands infected. *S. aureus* was responsible for 40% of all intramammary infections (Watson et al, 1990). *P. haemolytica* is also an important cause of mastitis in sheep. Udder damage from mastitis can cause a decrease in milk yield to below the 500 ml/day considered necessary for adequate survival rates in lambs (Jordan and Mayer, 1989). Lamb growth rates during the first month after lambing can be reduced by as much as 20% by udder damage.

Infection of sheep flocks with the maedi-visna virus may be associated with a chronic indurative mastitis, which leads to suboptimum growth rates of lambs during the preweaning period (Van der Molen et al, 1985). Sheep flocks with a high prevalence of viral infection based on serological testing have a much higher incidence of indurated udders in the ewes and insufficient growth in their lambs than flocks that are seronegative for the virus (Van der Molen et al, 1985). The lesions of the udders of sheep from infected flocks are characterized by chronic interstitial indurative mastitis with abundant lymphoid proliferation.

The level of nutrition of ewes during late pregnancy and lactation influences lamb survival and growth rates of lambs (Jordan and Mayer, 1989). Ewes fed three levels of nutrition—110%, 90%, and 70% of maintenance requirements during the prenatal and postnatal periods—had daily milk yields of 1146, 1070, and 938 ml/day, with lamb growth rates of 178, 169, and 138 g/day, respectively. The live weights of the lambs at 4 to 6 weeks of age were 10.2, 9.6, and 8.6 kg, respectively. Lamb survival rates from ewes fed at 110%, 90%, and 70% of requirements were 89%, 75%, and 73%, respectively (Jordan and Mayer, 1989).

Subclinical mastitis in ewes leads to a marked decrease in the milk yield and decreases the growth rate of lambs between the 5th and 20th days after lambing, when they are highly dependent on milk (Fthenakis and Jones, 1990). Routine palpation of the udder at lambing, weaning, and breeding by a careful shepherd can be a useful screening procedure to detect gross abnormalities of the udders of ewes, which may warrant culling because they are unlikely to provide sufficient milk at the next lactation (Watson and Buswell, 1984). Intramammary infusion of affected udders with sodium cloxacillin at weaning may reduce the incidence of palpable lesions by breeding time. Similarly, subcutaneous injection of tilmicosin at weaning helps eliminate subclinical mastitis and prevent postweaning mastitis (Smith and Tice, 1996). Intramammary infusion of ewes with cephapirin benzathine at the end of lactation can reduce the incidence of new infections early in the next lactation and can reduce the persistence of existing infections (Hueston et al, 1989).

Acute and subacute mastitis are problems in sheep dairy enterprises. The literature on udder health and on the clinical and epidemiological aspects of mastitis, including control of the disease in sheep dairies, has been reviewed (Dawe, 1990; Philbey, 1990).

Specific Lamb Causes

A number of characteristics of lambs are associated with their increased susceptibility to disease.

Congenital Defects

The frequency of defects in newborn lambs appears to be much less than in cattle, and they are not usually recognized as a cause of significant mortality (e.g., an American survey recorded 9 of 36 listed inherited defects in 21,000 Rambouillet lambs born over a 15-year period) (Ercanbrack and Price, 1971). Another estimate was 2% congenital defects for lambs compared with 0.5% to 3% for calves (Hughes, 1972). However, higher figures have also been quoted (Priester et al, 1970). The nature, cause, and diagnosis of congenital defects in lambs have been reviewed (Dennis and Leipold, 1979).

Inherited Defects

The known or strongly suspected inherited defects are shown in Box 16-13.

The diseases against which control programs have been mounted are corticocerebellar atrophy, photosensitization, spider lamb syndrome, and entropion. Selection against the defect can be practiced, but the selection pressure for profitable traits is likely to be high. Accordingly, there is great difficulty in conducting a genetic control program in a single flock. On the other hand, participation in a group breeding scheme (see the later "Genetic Management" section) may make the program feasible.

Sporadic and Environmental Congenital Defects and Infections

The defects known to result from the effects of noxious items in the environment are shown in Box 16-14.

There is a long list of sporadic defects in sheep. These have been presented for New Zealand (Hartley and Kater, 1964) and Australian merinos (Dennis, 1965).

Twinning

Although the mortality among twins is higher than among singles, the difference may be obvious only under extensive conditions, if the general mortality rate is already high. There is also a behavior problem, especially with merino ewes, which are inclined to walk away from one of a pair of twins, especially if it lacks vigor for some reason. However, many of the separations and subsequent deaths from starvation are in robust lambs (Stevens et al, 1982).

Surgical Procedures

Given the absence of the rare disaster at castration, this operation does not significantly alter the survival rate. Excessive blood loss is rare in young animals, even with knife castration and tail docking. Internal bleeding, when the spermatic cords are removed by traction rather than being severed with a knife, can occur; it makes a dramatic postmortem picture,

BOX 16-13

Inherited Defects

Hereditary chondrodysplasia (spider lamb syndrome) in the Suffolk and Hampshire breeds (Rook et al, 1988)
Cerebellar abiotrophy (Scott et al, 1994)
Corticocerebellar atrophy (Stamp, 1967)
Clinically similar disease in border Leicesters characterized by lesions in neck muscles
Inherited goiter in merinos and possibly Polled Dorsets
Ceroid lipofuscinosis in South Hampshires
Generalized glycogenolysis of Corriedales
Globoid cell leukodystrophy of Polled Dorsets
Multiple tendon contracture in merinos
Osteogenesis imperfecta
Mandibular underdevelopment of merinos and Rambouillets
Epidermolysis bullosa in Suffolks and South Dorset Downs
Dermatosparaxia in merinos
Bilateral lip cleavage in Texels
Redfoot in Scottish Blackface
Inherited photosensitization in Corriedales and Southdowns
Atresia of gut segments
Entropion in several British breeds of fat sheep
Prolonged gestation and fetal giantism in Karakuls (also caused by poisoning with *Veratrum californicum* or *Salsola tuberculata*)
Hairy birth coat*
Cryptorchidism (Claxton and Yeates, 1972)
Scrotal anomalies*
Crooked legs*
Ventricular septal defect in Southdowns (Dennis, 1970)

*Genetic controllability has been reported.

BOX 16-14

Defects Resulting from Noxious Elements in the Environment

Hairy shakers or border disease caused by a virus
Congenital toxoplasmosis*
Brain deformity (porencephaly) caused by bluetongue virus
Arthrogryposis and hydrencephaly caused by Akabane virus infection
White muscle disease caused by vitamin E-selenium deficiency in the diet
Poisoning by weeds in pasture (e.g., *Veratrum californicum*, *Astragalus* and *Oxytropis* sp., *Lupinus sericeus*)
Poisoning by farm chemicals, especially parbendazole and cambendazole
Experimentally by high environmental temperatures
Enzootic ataxia (swayback) caused by copper deficiency in the diet
Goiter caused by a deficiency of iodine in the water supply or goitrogenic plants

*Dubey JP, Kirkbride CA: *J Am Vet Med Assoc* 195:1715-1716, 1989.

but the overall importance of these losses is small. Strong rubber rings (elastrators) are commonly used for docking and castration and to avoid blood loss, but their use can lead to tetanus in unvaccinated flocks. The behavioral and cortisol responses of lambs to tail docking and castration during the first week after birth have been examined (Mellor and Murray, 1989).

Health Management to Optimize Perinatal Survival of Lambs

Principles of Preventing Neonatal Lambing Losses

An overall control program to suit all circumstances is difficult to propose because the relative importance of the causative factors varies so much from place to place, from farm to farm, and even within one farm from year to year. The management system may be intensive, indoors, or extensive, and the amount of care and the nature of the husbandry can vary considerably. However, the principles are similar. The major requirements for a high survival rate are birth weight near the optimum for the breed, good accumulation of protective immunoglobulins in the udder, easy birth, protection from cold, and maximum contact between ewes and lambs during the first 12 hours after birth to ensure adequate passive antibody transfer and development of the maternal bond. Almost all lambs survive if given adequate obstetric assistance, warmth, and food (Alexander, 1984); however, infectious diseases are not controlled so readily in intensive systems (Eales et al, 1985; Scott and Gessert, 1996b). In general terms, a program should at least give consideration to each of the following.

Close Supervision of Lambing. This can detect ewes with dystocia early during second stage labor and can provide assistance with the birth. This principle can be practiced by close examination of the ewes at pasture three times a day, by continuous supervision of groups of ewes indoors, or by any variation between these management practices. The farmer must be instructed in the technique of providing aseptic assistance with parturition where the introduction of disposable arm-length plastic gloves has proved very beneficial. The ewe's teats should be examined immediately after birth of the lambs to ensure that colostrum is present and that the teats are patent and not plugged with teat plugs. In indoor lambing sheds, it is empirically recommended that the navels of all lambs should be dipped in a tincture of iodine solution as soon after birth as possible and again 4 to 6 hours later. When this procedure is correctly undertaken, the umbilical remnant is dry and brittle by 36 hours old and provides an easy method for monitoring routine preventive measures on the farm.

Close Supervision of Ewe and Lamb Immediately After Birth. This helps ensure proper mothering. The amount of activity required varies with the mothering tendency of the ewe. The objective is to ensure that the lamb receives an adequate amount of colostrum in the first few hours after birth and then receives sufficient energy to maintain it through the sensitive first few days when it is susceptible to hypoglycemia. Lambs require 180 to 210 ml/kg body weight of colostrum during the first 18 hours after birth in order to provide sufficient energy for heat production and enough immunoglobulins (Mellor and Murray, 1986). Ewes that are well fed during late pregnancy produce more colostrum than their lambs need; those with singletons have

enough for a second lamb, but, in most underfed ewes, the lamb's requirements for colostrum exceed the ewe's production. Colostrum can be readily obtained and stored for subsequent use. Bovine colostrum is a good alternative source of immunoglobulin for lambs (Eales et al, 1982b). However, in some cases severe anemia occurs in lambs fed bovine colostrum because of the presence of immune complexes on lamb erythrocytes (Bernadina and Franken, 1985), but such cases are numerically unimportant compared with losses resulting from starvation and exposure. The risk from bovine colostrum-induced anemia can be reduced significantly by pooling colostrum from four or more cows and freezing aliquots for subsequent use.

In temperate areas where winter housing is practiced, ewes are confined to pens or buildings to provide protection from the environment. However, crowded conditions can sometimes lead to poor maternal behavior and lack of a ewe-lamb bond early enough. Ewes lambing in crowded conditions are often unable to isolate themselves from the flock and may be interfered with by other ewes, or their lambs may become separated and be deserted (Gonyou and Stookey, 1985). Under such intensive lambing environments ewes are confined in pens 1.3 × 1.3 m with their lambs for the first 24 to 36 hours to promote a good ewe-lamb bond.

There is a strong bond between mother and young in sheep, and it is usual for ewes to repel strange lambs once the bond with a newborn lamb has formed, within the first few hours after life (Gonyou, 1983/1984). As a result, lambs are normally fed exclusively by their dams, which is an obstacle to fostering orphan lambs or lambs born as multiples that are not being reared successfully by their dams. Fostering techniques have included ewe restraint, own-lamb odor transfer, and odor-masking agents (Alexander et al, 1987; Basiouni and Gonyou, 1988).

The fostering of alien lambs onto ewes can be facilitated by the use of restraint devices in pens 1.2 × 1.2 m, initiated 2 to 3 days after parturition and followed by a period of unrestrained cohabitation as a pair and subsequent exposure to groups of females (Price et al, 1984; Martin et al, 1987).

Odor specific to individual lambs enables ewes to discriminate between their own and alien lambs (Alexander and Stevens, 1982b). Many postpartum ewes adopt a single alien lamb in addition to their own if the alien lamb is wearing a jacket impregnated with own-lamb odor. Maternal acceptance of alien lambs is facilitated when own-lamb odor is transferred to alien young through the pelt of a dead lamb or on cloth jackets previously worn by the ewe's own offspring (Holmes et al, 1989). The transfer of odor from own to alien lambs with a cloth or hessian jacket leads to a relatively high acceptance rate of more than 90% when substituting a single alien lamb for a natural lamb (Alexander et al, 1985). Adoption rates are lower, about 70%, in "add-on" fostering, a procedure in which an alien lamb is placed in the care of a ewe in addition to her own single lamb (Alexander et al, 1985). Ewes bearing single lambs tend to accept only one lamb, whether or not odor transfer fostering techniques are used (Holmes et al, 1989). The use of nonspecific, strong-smelling substances to mask the odor of alien lambs is not successful (Alexander and Stevens, 1982a).

Fostering can be facilitated by the use of jackets soaked in birth fluids and by cervical stimulation (Basiouni and Gonyou, 1988). The use of washing of lambs combined with close confinement appears to be an effective method of fostering lambs onto ewes, especially within the first day or two after birth (Alexander et al, 1983). The traditional shepherd's method of draping the skin of the dead lamb over the foster lamb is almost 100% effective (Alexander et al, 1987).

It is important to avoid excessive, officious interference, especially with merino ewes and particularly with maiden ewes. A heavy-handed, bustling attentiveness may cause more disturbance of mothering than it prevents.

Provide Protection from Inclement Weather. This can be done by lambing in clement weather or by shedding or using other protective wind baffles. These include leaving rows of hay bales arranged to give shelter from prevailing winds and cutting swathes through a standing cereal crop or overgrown pasture (Egan et al, 1976). The provision of windbreaks around the edges of large paddocks has little value; the ewes and lambs are too far away to be protected. In effect, they need to get in among the protective material. In very hot climates the two critical needs are proximity to water and overhead shelter from the sun. Shedding may be performed in the shearing shed or in a shelter constructed especially for the purpose. The latter has obvious advantages, especially if the shed can be put to other uses in the lambing off season.

A system for the detection and treatment of hypothermia in newborn lambs can improve the survival rate (Eales et al, 1984; Eales et al, 1982c). Most lambs become hypothermic within 5 hours or at more than 12 hours after birth. Hypothermia in the first 5 hours of life is most commonly caused by a high rate of heat loss from the wet newborn lamb, whereas a depressed rate of heat production consequent to starvation is the most common cause in the older lamb. Twin and triplet lambs are more susceptible to hypothermia than singles because of lower body energy reserves; the ewe takes longer to lick dry two or three lambs, and the milk requirement of two or three lambs is higher than that of a single lamb and starvation is more likely.

The body temperature of any weak or suspect lamb is taken with an electronic thermometer (Eales et al, 1984). Lambs of any age with mild hypothermia (37° to 39° C [99° to 102° F]) (Table 16-6) are dried off if necessary to reduce heat loss, given ewe or cow colostrum by stomach tube, and placed in a sheltered pen with the ewe. Lambs less than 5 hours of age with severe hypothermia, lower than 37° C, are dried off and given an intraperitoneal injection of 20% glucose at a temperature of 39° C. A large lamb (more than 4.5 kg) is given 50 ml, a medium lamb (3 to 4.5 kg), 35 ml, and a lamb less than 3 kg, 25 ml. Hypothermic lambs are then placed in warming pens measuring 2 × 2 m made of horizontally laid straw bales, two bales high. The pen is divided into two chambers by a sheet of weld mesh on which the lambs lie. Warm air at 38° to 40° C (100° to 104° F) is blown into the lower chamber from a domestic heater, and a sheet of polythene fitted over the entire pen retains the heat. When the lamb's temperature reaches 37° C (99° F), it is removed from the warmer and immediately fed ewe or cow colostrum by stomach tube at a rate of 50 ml/kg. Any lamb that is vigorous and able to suck is returned to its ewe in a sheltered pen and monitored over the next several hours. Colostrum can be hand milked from the ewe after the administration of oxytocin.

Adequate Nutrition. In many prolific flocks, adequate nutrition necessitates supplementary feeding of ewes during late pregnancy. Alternatively, improved nutrition can be provided by moving them faster through a paddock rotation system, or even by advancing or delaying lambing by 4 or more weeks.

Surveillance for Dystocia and Shelter and Mothering Assistance. This requires a significant concentration of effort during the lambing period. Ewes getting close to lambing must be brought into an intensive care group and the ewes and lambs passed out of this group as soon as possible, but only when the dangers of starvation and exposure are

TABLE 16-6

Treatment of Hypothermic Lambs

Body Temperature	Age	Other Signs	Treatment
37°-39° C	Any age	—	Towel dry; tube 50 ml/kg warm colostrum; shelter with ewe
<37° C	<5 hr	—	Towel dry; warm box until temperature is 37° C; then tube 50 ml/kg colostrum; careful observation with ewe
< 37° C	>5 hr*	Head up	Hypoglycemic; stomach tube 50 ml/kg colostrum, then warm box to 37° C, stomach tube again; careful observation with ewe
< 37° C	>5 hr*	Comatose or convulsing	Intraperitoneal (IP) 20% warm glucose at 10 ml/kg body weight, then warm box to 37° C and stomach tube; careful observation with ewe

From Henderson DC: *The veterinary book for sheep farmers*, Ipswich, 1990, Farming Press Books.
*Do not warm up lambs more than 5 hr of age without first treating for hypoglycemia (either by tubing with colostrum or IP glucose).

past. In shed lambing this is an obvious maneuver, but it can also be used in pasture lambing by a technique of "drifting" lambs and ewes away from the lambing group and into new rearing groups, which are watched less intensively.

Adequate Milk Supply. Measures to ensure an adequate supply of milk for the lambs when they come as singles or twins include prelambing inspection of the ewe's udders. A high incidence of caseous lymphadenitis, with lesions occurring in the supramammary lymph nodes, or of chronic mastitis can also have adverse effects on lamb survival. Udders surrounded by excessive wool, very pendulous udders, or grossly distended teats also reduce the availability of the milk supply. Ewes with any of these defects should be culled at the earliest opportunity. Observations of teat-seeking behavior of newborn lambs have revealed that they use surface texture and a degree of surface yield as cues for locating the teat (Billing and Vince, 1987a,b). There is a wide range of variation among breeds in several aspects of neonatal lamb behavior (Slee and Springbett, 1986). Those breeds with effective udder-seeking behavior tend to have a good resistance to hypothermia and low perinatal mortality. It is suggested that udder-seeking and early sucking behavior may be influenced genetically (Slee and Springbett, 1986). Finns and merinos have deficiencies in udder seeking and in resistance to hypothermia, and they are considered unsuitable for lambing outdoors in cold climates (Slee and Springbett, 1986).

Choice of Lambing Method Used. On a particular farm, this is largely dependent on the financial gains to be achieved. Managerial expertise is also important. For example, some farmers are excellent in their ability to identify ewes coming up to lambing. Unless there is reasonable expertise at this, the number of ewes that need to be under intensive surveillance at one time becomes so great that the shed required becomes too big to be financially practicable. Many of the problems of intensive lambing could be eliminated by an efficient system of estrous synchronization or batch lambing. An outdoor penning or indoor shedding system requires disinfection of pens between ewes to avoid cross-infection of neonatal infections, but this is rarely done under commercial conditions unless there is an existing infectious disease problem. Manual assistance to an ewe with dystocia requires hygienic precautions. Intensive lambing practices without the farmer appreciating the need for great care with these activities could lead to serious losses.

Ability as a Shepherd. This is the single most important factor in preventing lambing losses, but at present a more important restricting factor is the relative absence of people to work in this and other agricultural activities.

Financial Gain. This is the final criterion, but some factors need to be included in it. For example, if a particular farmer is anxious to increase the flock size without purchasing sheep, the value of twins is raised and the value of individual animals saved also rises. Because of the need to capitalize earning power when possible, the opportunity of increasing stocking rate must be kept in mind constantly, but the return to the new management technique must be set against its cost. The price of additional lambs has to be managed so that the cost of additional labor and the interest on the capital invested in a lambing shed are not greater than the value of the lambs provided. Thus the whole project becomes much more important when the prices of wool and mutton are high and all farmers are seeking to enlarge their flocks.

Availability of Capital. This may be as important as the availability of labor. Unless capital is available for shed construction or another similar device, it may be impossible to proceed.

Other Factors. Those that affect the time of lambing may have managerial and financial implications that outweigh inclemency of weather problems. For example, autumn breeding and spring lambing have the advantage of high fertility but the disadvantage of higher neonatal losses. The net effect of switching to spring breeding and autumn lambing may be nil in terms of lambs on the ground, but a seasonal poor supply of feed in early summer may mean that a high lambing percentage may be offset by a poorer growth rate in early lamb life. In North America, spring lambing coincides with higher market lamb prices.

Accurate Records. The overriding consideration in any flock health program is the need to know the forms of neonatal loss and their important causes. On some farms, it is not possible to do this because the necessary records are

not available. In most cases, a count is kept of lambs marked and lambs weaned, but it is usually necessary to run a surveillance year to accumulate data on which to base a decision that the reproductive loss is the result of poor fertility or high neonatal mortality. The records needed include the following:

- Careful, accurate pickup at least once daily of all dead lambs
- Careful, accurate necropsy examination of a large sample of dead lambs
- Accurate head count of ewes that lamb and the number of lambs born

This form of examination should be accompanied, as discussed earlier in the section on reproductive inefficiency, by a program including the use of a ram harness to mark ewes in estrus and pregnancy diagnosis. A complete examination is the only way of avoiding an error when both ends of the reproductive cycle have errors.

Specific Measures to Prevent Neonatal Lambing Losses

A completely successful program to cover all eventualities, without regard to cost effectiveness, is not likely to be a desirable objective. The following are programs of increasing sophistication and cost. The program likely to be chosen is the one most suited to the economic status and managerial system of the property (Beggs and Campion, 1966).

Extensive Lambing. Leaving the ewes to their own devices and examining them once daily at most is a time-honored and satisfactory method if sheep grazing systems are extensive. To do anything more than this would be financially impractical in most cases, because the usual mortality under this system of management is low. Predators are one of the main causes of loss, and shepherding during the day and corralling at night are about the only practical preventive measures. Changing the lambing date to avoid the inclement weather of late winter and early spring offers some attractions but has the serious disadvantage of missing the heightened fertility obtained by mating in early autumn. The net effect is likely to be no gain. Selection for more motherly ewes would be a worthwhile objective in a timid ewe flock, but care would be needed to avoid losing some of the fine wool characteristics. The use of sheltered paddocks and pastures with the best available feed are routine recommendations for lambing ewes and may be applicable here. The system has the advantage of avoiding excessive interference with the ewes.

Intensive Lambing at Pasture. In this system the ewes are run at pasture but at a high stocking rate with surveillance at least twice and preferable three times daily. This provides an opportunity for the early correction of dystocia and mismothering and allows a more accurate identification of lambs and their dams. The system is improved by having a series of small fields available as close as possible to the house to permit almost continuous observation. Maiden ewes should have the closest surveillance and if feed can be saved in the paddocks before lambing commences, this is an advantage. Shelter provided by putting out hay bales in rows or by cutting swathes in long pasture, especially phalaris or an oat crop, is much used by the sheep and is a great help (Egan et al, 1972). Lanes must be cut in the long grass or cereal crop; this enables the sheep to move about freely. Failure to do so can result in ewes and lambs being fatally separated. One advantage of this system is the number of lambs that can be salvaged that would otherwise die of starvation and exposure. These practices, however, require a vehicle for use as an ambulance, a makeshift nursery in a shearing shed, heat lamps and infrared lamps, hot water bottles, cartons, bottle-feeding equipment, and a supply of stored colostrum.

This system is the one most used and most recommended for areas with year-round pasture for average circumstances. It is possible to detect and correct dystocias and mismothering problems, but there is difficulty in catching the subjects, so that it is sometimes necessary to drive the particular group all the way to the nearest sheep yards. There is also the disadvantage that all the ewes must by inspected. There is no opportunity to separate the flock into ewes that are about to lamb within the next few days and those that are still distant from lambing. This wastes time, and, if the lambing percentage is good anyway, there is a tendency to dispense with the inspection, especially when other matters are pressing or when the weather is bad. However, these tend to be the times when the need is greatest. On the other hand, doubling the amount of time taken in the inspection may offer little improvement in the lambing percentage.

Drift Lambing. This technique is used to overcome the disadvantage of having to examine all the lambing ewes at every inspection. About six small paddocks are needed; the ewes that are reasonably close to lambing are put into the system each day and the nonpregnant ones moved on, leaving the ewes with recent lambs behind. Those left behind are watched to make sure that a firm ewe-lamb bond is established and that both the lambs and ewes are well. After 3 or 4 days they are moved out to other larger groups. The ewes are fairly easy to move in the autumn, when feed is inclined to be short and some supplementation is given by feeding out. In spring, when there is ample pasture available, the ewes are not easy to move. Drift lambing can be combined with shed lambing as an emergency program to be adopted when the weather is bad and losses are likely to be high. One thing is lacking in the drift system: protection from bad weather. The small size of the paddocks makes feeding, surveillance, and identification much easier.

Outdoor Pen Lambing. In this technique the ewes at the point of lambing are moved out of a set of drifting paddocks and into a set of individual pens. All ewes might go into a pen, or perhaps only the problem ones that present mismothering or dystocia difficulties. If all ewes go through, they might be put in individual pens before or after they have lambed. The former requires a sharp midwife-type eye; some farmers have it, some do not. A technique used to improve the accuracy of selection is to use a ram marking harness during the mating period and to separate the ewes into groups of 1-week's matings. These groups then can be moved up to the shed in rotation as their anticipated lambing date arrives. Those people who are good at selecting ewes that are close to their time are valuable, almost essential, for the efficient running of an intensive lambing operation. Experience is also valuable. Some of the points on which the selection of ewes is based are (1) relaxation of pelvic ligaments, as indicated by "falling in" of the tail and pin bones, (2) slackness of the vulva and surrounding skin, giving the vulvar lips a boxing glove shape, (3) bright red to purple vulva and posterior vagina, and (4) firmness and swelling of the udder with division of the udder into two halves evident, and the presence of colostrum. To be most effective in identifying these criteria, the tails of the ewes must have been docked and previously shorn.

For both outdoor and indoor pen lambing, it is usually safest to have a group pen into which the ewes go first (about 20 to a pen). From here, the individual ewes are selected for the lambing cubicles.

The number of cubicles required varies with the inefficiency of the operator in detecting impending parturition. An average operator can manage one cubicle per 20 ewes to lamb. A highly skilled person can manage one cubicle per 35

ewes. A common practice is to limit shed lambing to maiden ewes, in which the greatest losses occur and the most gains are to be made. As efficiency increases and more ewes can be handled through the shed, additional age groups are added.

Again, there is the disadvantage that inclement weather could still cause many deaths but, if the pens are carefully located or protection is provided against strong winds by natural or temporary artificial windbreaks, these losses can be reduced. The result is not as good as that obtained by providing a shed, but the capital cost of the latter is avoided. The costs and returns have been identified (Clarke, 1977); the profitability of shed lambing depends on the high value of sheep.

Shed or Indoor Lambing. Like outdoor pen lambing, this system provides an individual pen or crate for each ewe as she lambs. The ewe and lamb stay in the pen sufficiently long to ensure that the mothering bond is established and that the lamb has its quota of colostrum. Lambs lacking in vigor can receive special attention. They are then moved out to the flock, the pen is cleaned and possibly disinfected if there is any indication of need for it, and the next ewe is admitted. The provision of a shed is a considerable economic investment; it is generally used when lambs are born during cold, wet, and windy weather. One of its principal advantages is that it gives shelter to the workers when they are providing assistance to the animals. It is a great advantage if the shed can be used for several purposes; at the least it should be of the simplest and cheapest construction.

As soon as the lamb is born, it is kept under observation to make sure it stands and sucks. The udder and teats of the ewe must be examined to ensure the presence of colostrum and to remove any teat plugs. Lambs that are lacking in vigor profit from assistance with sucking and, if not successful, feeding of an appropriate volume of colostrum (50 ml/kg) by stomach tube. These lambs should be checked for progress about every 6 hours. If there is a limit to the number of ewes that can be handled through a shed, preference should be given to maiden ewes because they need more assistance than older ewes. One possible extension of a shed lambing program is the harvesting of the lambs at early weaning (e.g., 3 weeks) and artificially rearing them. The way is then clear for two crops of lambs each year and two uses of the shed. However, artificial rearing of lambs is costly and such lambs are prone to numerous problems, including abomasal bloat, and infectious diseases, namely cryptosporidiosis, coccidiosis, and respiratory disease.

General Provisions in All Lambing Systems

The systems just described are directed at the principal causes of loss at lambing: inclement weather, poor mothering, insufficient food supply, lack of assistance for ewes that are in trouble, and deaths caused by predators. All of these programs need to have specific provisions to control specific causes of loss, if and when they occur (Box 16-15).

Weather and Disease

In a Northern Ireland study, the occurrence of pleurisy and pneumonia in sheep slaughtered in the abattoir was correlated with the prevailing weather conditions. There was a strong correlation between lung condemnation because of pleurisy and pneumonia and inclement cold and rainy weather (McIlroy et al, 1989). Of the weather conditions such as rainfall, wind speed, temperature, and humidity, the most significant was wind speed (McIlroy et al, 1989). Both rain and wind reduce the insulating effect of the fleece and make the animals more susceptible to the effects of chilling, which can lead to pneumonia. This suggests that sheep should be protected from the extremes of both wind and rain. In the United Kingdom, housing of the ewe flock in winter can prevent pasture damage, reduce ewe and lamb losses, increase output, and improve working conditions for the shepherd (Linklater and Watson, 1983). The essentials for sheep housing have been described (Linklater, 1987). Wind chill in sheep can be estimated from meteorological records (Mount and Brown, 1983).

BOX 16-15

Provisions to Control Lambing Losses

- Specific nutritional deficiencies of iodine, copper, selenium, and vitamin E
- Congenital defects conditioned by inheritance
- Specific bacteriologic, chlamydial, and viral causes of abortion and neonatal death from intrauterine infection
- Similar infections occurring postnatally
- Ewes with defective udders
- High incidence of dystocia caused by the inheritance of large-headed lambs or very large lambs
- Other causes of ewe-induced lamb losses, particularly ring womb, uterine prolapse, and vaginal prolapse
- Factors that contribute to vaginal prolapse, including ring womb or dystocia, estrogens in the diet, multiple births, excessive body condition score of ewes, high-fiber diet, crowding at feeders, and idiopathic causes
- Trauma and blood loss resulting from dystocia, tail docking, and castration
- Protection against predators

PRODUCTION MANAGEMENT

Nutrition on Pasture

Good sheep management depends more than anything else on the judicious use of pasture. Pasture management is a science in itself and is not presented here. However, it is important to provide some indication of the types of factors to be considered in a pasture management program. Box 16-16 lists factors that influence the pasture as feed.

Animal Management: Using the Feed

There are many interactions among all the factors in Box 16-17, among them the uncontrollable variables of climate, environmental disasters, including fires, floods, and drought, and the site factors of geographic location. It is not possible to do much more than generalize about the subject without access to a computer simulation model, which enables the effect of variations in each of these variables to be tested. A good review of the subject has been published (White and Morley, 1982).

In general terms, pasture management for sheep requires that heavy spring and autumn growth be heavily stocked, saved as standing feed, or hayed. In poor growth periods the standing forage and hay are used to subsist the sheep through the period of undernutrition. Special attention is required in breeding sheep to provide optimum nutrition at the critical periods of breeding, late pregnancy, and lactation, especially the first few weeks. For lambs, the critical period is from weaning until the time of sale. These are the periods when supplementary feeding with grain or concen-

BOX 16-16

Pasture as Feed

Composition of the pasture: livestock graze preferentially, selecting, and consuming the species or individual plants or parts of plants that they like, such as grass over legumes, timothy or brome over orchard grass, white clover or perennial rye grass over most everything else, juvenile over mature plants, and leaves over stems, and only reverting to the less desirable species if they must
Use of fertilizers
Availability of irrigation
Subdivision of pastures: this requires sturdy fencing with provisions for securing it to the ground surface to keep out the coyotes and dogs
Pasture rotation systems
Forage conservation from pasture: hay and ensilage
Forage cropping
Supplementary feeding
Use of hay fields or stubble fields

BOX 16-17

Using the Feed

Stocking rates. The number, size, and shape of paddocks and the time that sheep spend in the paddocks are major factors in the development of an effective and controlled grazing system. The number of paddocks, their size, and the number of days of grazing depend on allowing sufficient regrowth time for each factor to regain grazeable maturity. The system must be designed to keep the forage healthy.

Movement of sheep from paddock to paddock and access to water. Grazing paddocks should be planned so that sheep can move from paddock to paddock with ease. This can be accomplished by having all paddocks connected to a single, central source of clean water. The water, salt, and minerals, together with any supplemental feed troughs, should be located in a fenced watering corral that is connected by gates or lanes to all paddocks. Ideally, handling facilities should be adjacent to this watering corral.

Composition of the grazing flock. Breeding versus dry sheep, date of breeding, date of weaning, date of marketing.

Disease control. Restraints on animal movement.

trates is most likely to be needed. On farms with mixed enterprises, grain growing is an advantage because of the stubble that becomes available, and beef cattle are also helpful in that they permit better management of the pasture, especially if it is overgrown.

By determining the BCS of a representative sample of sheep at strategic times during the reproductive cycle, it is possible to assess the nutritional status of the animals and to make the necessary adjustments in the ration, including supplementation at pasture to satisfy the nutrient requirements of the particular stage of the production or reproductive cycle. This was discussed in detail earlier.

Poisonings

Poisoning may be caused by fungi on grasses (e.g., facial eczema, possibly rye grass staggers). Toxic agents in pasture grass (e.g., phalaris, fescue, and *Panicum* sp.) may be present. In special circumstances, any lush grass may contain toxic amounts of nitrate (converted in the rumen into nitrite).

There is a long list of poisonous weeds that can affect sheep. Two important groups are the *Astragalus* sp., because of their palatability and extensive occurrence in North America, and plants containing pyrolizidine alkaloids and other hepatotoxic agents in Australia and South Africa.

Cyanide poisoning is no longer common because the common plant causes, especially sorghum and Johnson grass, are not grown much. Large areas of sheep country can be rendered unfarmable by the presence of subterranean clover and certain red clovers containing estrogens, or by a variety of plants containing high levels of oxalate. *Brassica* sp. are also used to extend pastures in temperate climates into December and have the potential to cause goiter.

Nutritional Deficiencies

Phosphorus, copper (primary or secondary resulting from a high molybdenum intake), cobalt, iodine, and selenium-vitamin E deficiencies are causes of naturally occurring diseases. Zinc deficiency has been produced experimentally. Vitamin D could be deficient in housed sheep, but this is unlikely in grazing animals. Animals on pasture during long droughts may become vitamin A deficient, but this is unlikely given the long hepatic storage of the vitamin.

Miscellaneous Dietary Diseases

A number of dietary diseases occur in sheep, and their prevention requires constant surveillance of the diet to ensure that the factors contributing to their occurrence are minimized. The details of control and prevention are presented in other texts. Bloat is much less common in pastured sheep than in cattle. Urolithiasis is a more common occurrence, especially in some areas where silica uroliths prevail, and calculi containing benzocoumarins occur on diets high in subterranean clover. Periodontitis and premature wear of sheep teeth achieve a high prevalence in some areas, especially New Zealand, and cause premature culling. Pregnancy toxemia commonly occurs because of an inability to maintain nutritional status in late pregnancy in a bad season. Hypocalcemia is also an important disease that occurs most commonly in the late pregnancy and less commonly in early lactation. It is rarely accompanied by hypomagnesemia.

Health Management in Lamb Feedlots

In the United States, approximately 6 million lambs are marketed for slaughter annually. Feedlot lambs originate from many different flocks of varying sizes and enter the feedlot weighing about 30 to 32 kg. They are fed in the feedlot for 45 to 60 days and marketed at 50 to 55 kg (100 to 120 lb). Average daily gains range from 0.2 to 0.3 kg. The diets are grain based, and a period of conditioning of 21 to 28 days to the high-level grain diets is commonplace to minimize the incidence of lactic acidosis and enterotoxemia. Systems of early weaning and finishing of lambs have been developed that have particular importance for intensive systems of frequent breeding or in systems in which ewes are milked for the sale of milk for processing (Orskov, 1987). The need for protein supplementation depends on the previous nutrition of the lambs. Those that have experienced a period of low-level nutrition or undernutrition have a greater requirement for undegraded dietary protein than

well-fed lambs at the same live weight. The nutritional and economic aspects of feeding lambs in feedlot conditions in Australia have been described (Hodge, 1983). Population mortality in lamb feedlots ranges from 1.5% to 3.0% (Pierson and Kimberling, 1981).

The consumer is demanding lean lamb rather than fat lamb, and production methods to increase lean and reduce fat in lambs have been reviewed (Glimp and Snowder, 1989). Crossbreeding and selection within a breed can increase the percentage of lean in the carcass. Selection for rate of gain should also improve the lean-to-fat ratio at a constant weight.

Reliable and useful data on disease prevalence in sheep feedlots are not readily available. The data that do exist are based on small numbers of sheep in small flocks, with mixed lots of age groups and no data on the numbers at risk (Moteane et al, 1979).

A survey of diseases and their associated costs in two Colorado feedlots in 1985 and 1986 revealed that the most prevalent diseases were pneumonia (4.9%, 13.0%), lactic acidosis (3.3%, 7.6%) enterotoxemia (3.1%, 1.49%), and transport tetany (0.48%, 2.4%), respectively, in each of the two feedlots (Salman et al, 1988b). Diseases with the highest average death loss causes in one feedlot were pneumonia, enterotoxemia, and acidosis; in the other lot, the highest average death loss causes were pneumonia, enterotoxemia, acidosis, and transport tetany. The prevalences of the other diseases in each feedlot were as follows: urolithiasis (0.50%, 0.35%), rectal prolapse (0.35%, 0.31%), salmonellosis (0.01%, zero), enteritis (0.10%, 0.02%), polioencephalomalacia (0.04%, none), tetanus (none, 0.01%), and other (0.57%, 0.60%). One feedlot had a lamb mortality of 2.2%, the other 3.1%. There was a large difference in the incidence of diseases between the two feedlots and in the expenditures for disease prevention (Salman et al, 1988b). This difference may have been the result of differences in management expertise, health management programs and schedules, and other factors that were not identified. This provides an opportunity for the veterinarian to examine the health management techniques used and to make changes to eliminate unnecessary costs.

Pierson (1970) has described a flock health management program in a lamb feedlot that reduced death losses from 4% to 1.5% in the first year. The greatest loss was associated with management and poorly designed corrals. A weekly visit of 2 to 4 hours was made during the feeding season of August to the following July. An accurate record of all health data was kept and updated at each visit. All newly arrived batches of lambs were examined closely for evidence of disease, a close watch was kept on lambs in the hospital area, and necropsies were performed on dead lambs whenever possible.

A suggested health management program for lamb feedlots emphasizes control of the common diseases such as lactic acidosis, enterotoxemia, and pneumonia. Each lamb is identified with a paint brand according to its group and sorted into groups according to size. At 48 hours after arrival, the lambs are vaccinated with *C. perfringens* toxoid. Each lamb is treated with levamisole, fenbendazole, or ivermectin. An implant of an anabolic agent is given. A booster dose of the toxoid is repeated in 2 to 3 weeks. Producers and veterinarians must adhere to the withdrawal times before the slaughter of treated lambs. The lambs are placed on the finishing ration by gradually increasing the level of concentrate in the self-feeding systems from 10% to 90% over a period of 21 to 28 days to avoid lactic acidosis and enterotoxemia. Antimicrobials may be added to the feed and water for the first 2 weeks to control the incidence of pneumonic pasteurellosis, but there is no evidence based on clinical trials that they are cost effective.

In such a program it is necessary to keep accurate records of the losses and expenditures related to health maintenance. If possible, body weights at entrance and sale, and the gain related to the weeks required to gain it, should be used in addition to deaths to indicate to the owner how well the health program is succeeding. Because the profitability of a feedlot depends on the efficiency with which the capital investment and the heavy recurring costs of labor are used, one of the two critical indexes is the speed with which lambs go through the lot. Thus inadequate feeding, climatic stress, and chronic disease become greatly important.

Among the important sources of loss are those that occur during transit to the lot. The lambs may become exhausted and go down to be trampled by the others so that they die of multiple injuries, exhaustion, or asphyxia. In hot weather, heat stroke may be an important cause of death. Most such problems can be prevented by avoiding overcrowding and by careful, easy-going transportation with regular stops where sheep are unloaded and offered feed and water.

Of the death losses, those caused by enterotoxemia are usually the greatest. Vaccination with *C. perfringens* type D toxoid as lambs go into the feedlot is almost mandatory (Pierson, 1967). Although this removes the bulk of the losses, some deaths can still occur during the first 10 days, and there would be an economic advantage in having the lambs vaccinated before they leave the home farm. The management technique of keeping the lambs on a low level of feed intake for the first 2 weeks in the feedlot may be necessary in a high-risk situation, but the effects are so unrewarding financially that a more positive approach is usually necessary. During their stay in the feedlot, the provision of a ration containing adequate roughage is an added protection against the disease occurring even in vaccinated lambs. Focal symmetric encephalomalacia is also a cause of significant loss, and a more intensive campaign against enterotoxemia should also reduce the occurrence of this manifestation of enterotoxemia.

Serious losses are sometimes caused by outbreaks of polioencephalomalacia. They present a problem, not only because of the ease with which they can be confused with outbreaks of enterotoxemia, but also because of uncertainty about the cause and prevention. A recent study has described an outbreak of polioencephalomalacia in fattening lambs fed a diet high in sulphur in which the high sulphur content resulted from the dietary components and not as the result of any mineral supplementation (Low et al, 1996). A routine preventive program would not appear to be necessary, but mass medication of the feed with thiamine may be necessary if cases occur.

To avoid the possibility of salt poisoning contributing to cases of a similar disease, it is essential that water be available at all times, especially when freezing disrupts supply. Salt, if provided, must be available at all times. An intermittent supply of salt combined with an intermittent water supply can cause salt poisoning.

Once in the feedlot, and with enterotoxemia under control, the other important causes of loss include pneumonia and septicemia caused by *P. haemolytica* and *Pasteurella trehalosi*. These diseases appear to be promoted readily by the stress of transport or by inclement weather. The metaphylactic administration of long-acting oxytetracycline has not proved cost effective during outbreaks of pneumonic pasteurellosis in lambs (Gilmour et al, 1988; Appleyard and Gilmour, 1990). In countries where psoroptic and other manges occur, dipping or spraying sheep as they enter the lot is almost obligatory. More recently, the introduction of effective ivermectins and milbemycins and related products allows control of psoroptic mange and gastrointestinal roundworms by a single subcutaneous injection.

During their stay in the lot, lambs are commonly affected by coccidiosis, which usually commences 2 to 3 weeks after they enter. Prevention depends on the hygienic arrangement of feeding and watering troughs to avoid their fecal contamination and early isolation and/or treatment of infected animals to prevent unnecessary contamination of the environment. The incorporation of a coccidiostat such as monensin, lasalocid, decoquinate, or amprolium is effective for the control of coccidiosis and improves the average daily gain. Internal parasitism is always a threat, and routine dosing with a broad-spectrum anthelmintic as the lambs enter the lot is recommended on the basis that it must be beneficial in almost every case. One of the problems arising when lambs do have diarrhea is their predisposition to blowfly strike (cutaneous myiasis) of the soiled area.

Because of the almost universal occurrence of wetness underfoot in outdoor feedlots and the high incidence of footrot in outside flocks, this disease is a major problem. Good drainage, the provision of roofing shelter, sandy soil, and mounds in the middle of the corrals all help, but severe outbreaks are inevitable. Although paring the feet and bathing are effective as a control program, because of the labor-intensive work they are hardly economical when 10,000 lambs are affected. The injection of large doses of either penicillin and streptomycin combination or oxytetracycline is expensive and much less effective when it is wet underfoot. The vaccines against footrot that are now available represent a more significant method of control but may prove cost prohibitive.

Urolithiasis can be a problem in lamb feedlots. Affected groups of castrated lambs usually come from well-defined geographic areas. The incidence seems to be higher in lambs fed diets with a calcium-phosphorus imbalance, usually a low level of calcium, and an inadequate water supply. The only generally applicable prophylaxis is the incorporation of 4% sodium chloride or ammonium chloride in the ration. Salt above this concentration unnecessarily depresses food intake. Other diseases likely to reduce effective weight gains are entropion and pinkeye (infectious keratoconjunctivitis). The former should have been dealt with at birth and certainly before the lambs enter the lot, and pinkeye is a summer disease although it may occur in an extended feeding season. There is no prevention other than early diagnosis and fast, effective treatment of early cases with intramuscular injection of long-acting oxytetracycline to prevent wider spread. Topical application of oxytetracycline ophthalmic powder is highly effective in the treatment of early lesions.

As well as traditional sheep feedlots, there are now those conditioning units in which sheep are held before being shipped overseas as live sheep, principally to Arab countries. They are, for the most part, adult male castrates with an emphasis on lean meat. Four- to five-year-old merino wethers are a common type of sheep for this trade in Australia (McAuliffe et al, 1978). The feeding program usually consists of hay, 0.4 to 1.0 kg/day, and pellets at the rate of 1.2 kg/day at the end of the period. The sheep are started on hay only, and the pellets are introduced and increased gradually to the full quota just before shipment. The death rate is claimed to be low (0.03%), where the principal causes of death are likely to be polioencephalomalacia and salmonellosis. A miscellaneous category includes clostridial infections and intoxications, trauma, transit tetany, toxemic jaundice, and urolithiasis.

Special Feeding Circumstances in the Sheep Flock

Survival Feeding and Management During Periods of Drought

During periods of drought, the veterinarian must provide advice on how to get through the drought with minimum dislocation to the farm as a business (Brightling, 1989). A major difficulty with costing a drought-feeding program is the uncertainty of the length of the drought. This can be overcome by estimating the probability of the drought breaking at various times and using these probability estimates to calculate an expected cost (Brightling, 1989). Sadly, the welfare of the sheep appears to be a secondary consideration.

For maximum economy and ease of handling, only grain is fed. Concentrate pellets may be used but add to the expense. Roughage is hard to handle economically, and in drought times is generally priced prohibitively. The sheep being fed grain are usually left in their paddocks and fed on the ground. In sandy country, where sand eating can cause heavy losses, troughs in the paddocks are necessary, or the sheep are yarded and fed in a feedlot system. Recommended amounts of feed are shown in Table 16-7. These are the amounts needed to support the sheep completely. They can be reduced if some natural feed is available.

TABLE 16-7

*Drought Feeding Table**

Class of Sheep	Wheat, Sorghum, Barley Grain	Oat Grain	Proprietary Sheet "Nuts"	Hay
Adult dry sheep including rams	350	400	450	750
Ewes in last 6 wk of pregnancy	450	550	600	900
Lactating ewes	650	750	800	1250
Lambs and weaners†	250	300	350	500

*Amounts in g/day/sheep.
†The amounts quoted are just adequate; a 33% increase would be safer.

Acidosis is always a threat, especially if sheep are put onto grain suddenly. All feeding changes should be made gradually; the grain should not be in amounts greater than those cited below, and it must be spread out so that all sheep can eat at the same time. Otherwise, the aggressive ones may get much more than their share. In the initial stages, it is important to feed every day to avoid acidosis, but, once the sheep are trained, better survival is obtained by intermittent feeding. A recommended regimen for dry sheep is to commence with 50 g/day, increasing to 350 g/day by Day 14. The feeding is then changed to every second day, and by Day 24 the sheep can be getting 1050 g (preferably 1400 g) every third day. Pregnant and lactating ewes get proportionally more (Table 16-7). Lactating ewes need some roughage, and 500 g/day would be a good investment. The economic advantage of knowing whether ewes are pregnant is most obvious during drought feeding.

In addition, there are a number of miscellaneous problems during drought feeding (Box 16-18).

Grazing on Lush Pasture or on Green Cereal Crop

Grazing on lush pasture or on green cereal crop are subject to two potential errors. On this type of feed, late pregnant and lactating ewes are likely to suffer a high prevalence of hypocalcemia, with or without hypomagnesemia. Little can be done to prevent the disease unless the sheep can be moved to a less lush feed, an unlikely prospect in a good spring. Most situations in which hypocalcemia is a probable hazard are dealt with by maintaining close surveillance and treating cases early. It is important to avoid sudden changes in feed or feeding practices in susceptible sheep.

In the northern hemisphere countries including areas of the United States and Europe, fall forage crops are becoming popular as means of extending the grazing season, which can be as short as 6 to 7 months compared to the 9-month grazing season in New Zealand, Australia. Fall annual crops include the winter grains (rye, wheat), and many *Brassica* sp. such as kale, rape, and turnip. *Brassica* sp. are easy to grow, are frost tolerant, and have a high carrying capacity (up to 1200 ewe grazing days/acre). Typically, the fall crops are grazed from late October to late November before a hard frost causes deterioration of the crop. Feed quality generally remains high throughout the feeding period, although the dry matter content increases with plant maturity.

Inadequate Diet in Late Pregnancy

This occurs commonly in low maintenance flocks because ewes are often mated to catch a spring or autumn flush when they are at the point of lambing. Failure of the appropriate rain to appear may lead to poor grass supply and the occurrence of pregnancy toxemia.

Genetic Improvement of Sheep Production

Sheep management systems have evolved over the centuries under conditions favoring the seasonal production of one or possibly two lambs. However, the productivity of the breeding flock can be improved through the use of breeds with special characteristics such as high prolificacy, rapid growth rate, milk production, and increased lean muscle mass. Further increases are possible through the use of specific crossbreeding schemes, selection within or between breeds, the

BOX 16-18

Problems During Drought Feeding

- The feed is usually simply spilled along a tortuous trail on the ground. Long-term feeding of the smaller grains on the ground may cause digestive upsets from the ingestion of surface soil. Troughing is preferable: 30 cm of double-sided trough for each three to four sheep.
- Drought feeding of parasitized sheep is poor economics, and all sheep should be dosed with a broad-spectrum anthelmintic before drought feeding commences.
- Lambs are a problem, especially if it is necessary to wean them early to save the ewe's life. They should not be weaned until they weigh at least 7 kg for merinos and 9 kg for crossbreds. At this weight, they should be about 6 weeks old. They should be fed roughage at all times; at the start at least 50% of the feed should be as chaffed roughage mixed with the grain. Vitamin A is probably best provided from the beginning; give 250,000 IU vitamin A at marking. A straight grain ration or poor hay is also low in protein, and the addition of 5 lb of linseed meal or 2 lb of meat meal/100 lb of grain is recommended. At this age, lambs need ample water, some good shelter from wind, and not too much space. A stocking rate of 600 to 800 lambs/acre is recommended. A hospital is needed for the weak ones.
- Lambing ewes should not have to compete too hard for their feed and, if possible, some roughage should always be available. Intermittent grain feeding then does not cause too much mismothering and desertion of lambs.
- Weaners and chronic "shy feeders" may not eat the grain and may die of starvation if they are not drafted off, driven up to the feed, and held on it. In any group on subsistence rations, there are some sheep that do not fare well. If losing them is to be avoided, they should be moved to a hospital group that is given special treatment.
- Sheep and cattle should not be fed together. The sheep are too exposed to traumatic injury.
- If urea is used, it should be fed with a carbohydrate-rich concentrate such as grain or molasses and given only when roughage is also fed. Feed no more than 10 g urea/head daily, and ensure that it is thoroughly mixed with feed.
- If the period of feeding is prolonged, the young sheep up to 1½ years of age need supplementation with vitamin A. Weaners at 3 months of age, if they have not had access to green feed, should receive 500,000 IU vitamin A, which should protect them for 6 months.
- Other specific nutritional problems that may be encountered are vitamin E deficiency, leading to cardiac and skeletal muscular dystrophy, and osteoporosis resulting from a high-phosphorus, low-calcium diet. Agalactia in ewes is also noted on purely grain diets. This can be corrected by the inclusion of some roughage in the diet.

mating of ewe lambs, and management techniques such as artificial photoperiod and hormonal treatments, which theoretically permit a lamb crop to be produced every 8 months or less (Ainsworth et al, 1985). Exploitation of higher productivity requires effective techniques for artificial rearing, an effective and simple recording system, adequate nutrition, and improved management procedures for control of predators, parasites, and disease. Although advances in research and technology in many of these areas have been comprehensively reviewed (Haresign, 1983; Treacher, 1987), a failure of technology transfer exists whereby perinatal ewe and lambs losses remain at unacceptable levels of 5% to 6% and 10% to 15%, respectively (MLC Yearbook, 1997), and as outlined elsewhere in this chapter.

All sheep breeding plans are intended to enhance the efficient production of one or more of the following products: wool, meat, milk, and pelts. The definition of the selection objectives is critically important for every sheep breeder because it determines the success of the sheep breeding enterprise. Every sheep producer is faced with a unique set of circumstances that can influence the choice of selection objectives. Different environments, different markets, access to different genotypes, and different personal goals lead sheep breeders to have a wide range of selection objectives (Robertson, 1983). The factors that should be considered in defining selection objectives and the variety of selection objectives that exist have been reviewed comprehensively (Robertson, 1983). In defining their selection objectives, sheep breeders should be prepared to assess their entire enterprise from its beginning in a systematically planned way. This includes a review of the resources available, a decision on the product desired (wool, meat, milk, pelt), consideration of adaptive traits (e.g., heat tolerance, parasite resistance, resistance to fleece rot, resistance to footrot), a long breeding season, consideration of the relative economic weightings of the products, a review of the genotypes available to obtain the optimum, and development of a breeding plan.

Increasing Prolificacy. Litter size or the number of lambs born per lambing is an important component of productivity in sheep, contributing more to the difference in total weight of lamb weaned per ewe than the growth rate of individual lambs (Bradford, 1985). It was traditionally thought, based on heritability estimates, that genetic variation in twinning rate or litter size was too low to justify trying to change it by genetic means. However, it is now generally accepted that genetic potential for mean litter size in sheep can be set at any desired level, from one to about three. Research interests are now centering on determining the levels of prolificacy that are optimum for different production environments, the most efficient means of achieving and maintaining those levels, and how to minimize variation around the mean (Bradford, 1985).

The optimum level of prolificacy is a function of environmental conditions and management systems. The optimum level is often not the maximum possible. Bradford (1985) suggested the mean values, shown in Box 16-19 for four different production environments, in terms of lambs born per mature (second or later lambing) ewe lambing. It is accepted that prolificacy is lower in first-lambing ewes, regardless of age at first lambing; it is generally uneconomical to delay breeding an ewe until she has achieved her full, mature reproduction potential.

The possibility of increasing litter size significantly can be achieved through the appropriate combination of breed resources, using prolific breeds of sheep, in one or two generations (Fogarty et al,1984a,b). However, the introduction of more productive genotypes into production systems is advantageous only if management is optimized to exploit the greater productivity. Ewes that give birth to and nurse triplets may produce 21% more milk/unit metabolic body weight, be 10% more efficient in the conversion of feed to milk, and produce 26% more kilograms of lamb/ewe in 42 days of lactation than ewes giving birth to and nursing twins (Loerch et al, 1985). This suggests that direct nursing stimulation of the mammary gland is responsible for the improvement in milk production observed when ewes nurse additional lambs. This aspect of husbandry practice must be considered carefully because overvigorous sucking by triplet lambs readily causes teat lesions and mastitis (Scott and Murphy, 1997). Feeding such ewes a moderate amount of undegradable supplemental protein such as roasted soybean meal or corn gluten may further stimulate milk production.

Despite the potential of new innovations and technologies, most have not been adopted to any great extent by the industry. The commercial failure of Fecundin highlights the gap between advances in reproductive biology and the ability of commercial sheep husbandry practices to cope with multiple litters, especially triplets.

Crossbreeding Programs. There are at least three possible methods available to effect genetic change in litter size in

BOX 16-19

Mean Values for Different Production Environments

EXTENSIVE LAMBING (GENERALLY ONCE A YEAR)

Forage is scarce and variable among seasons and years. Supplements are unavailable or uneconomic. The goal is single births. Twins are undesirable because the ewe will not have sufficient milk for the satisfactory growth of two lambs. Prolific sheep can be a serious liability under these conditions; the low birth weight of lambs, inclement weather, inadequate maternal care, and poor flock supervision combine to give a high lamb mortality.

If better forage is available, or there is potential for supplements, and seasonal rainfall supports forage for at least 3 or 4 months, the goal is twins from mature ewes but no higher multiples. Supplemental feed is often economically justified for ewes with twins but not for those with singles.

INTENSIVE LAMBING

Ewes are fed to meet nutrient requirements year round; there is supervised lambing with fostering of lambs, artificial rearing capability, or market for orphan lambs. This can occur on farms with good-quality pasture for 6 or more months of the year and with out-of-season accelerated lambing systems. The goal is a mean of 2 to 2.3 lambs/mature ewe/breeding period, with a maximum of 3.

Same management system as in the above example, except all lambs where there are more than 2/litter are reared artificially. Such a system is likely to involve confinement and accelerated lambing. The goal is the maximum number of viable lambs per ewe. A mean of 3 seems appropriate.

sheep: the introduction of inheritance from a prolific breed, selection within breeds, and the use of major genes, such as the Booroola. Genetic material from prolific breeds, such as the Finn, Blueface Leicester, and Romanov, in which high prolificacy is not apparently the result of a single gene, has been used in many countries to raise the prolificacy of local breeds or as the basis of new composite breeds (Hanrahan, 1987). Crossing the Finnish Landrace (Finn) or Romanov breeds with less prolific breeds increases the litter size by an additive effect (Hanrahan, 1987). The Cambridge breed is a highly prolific breed formed from foundation ewes selected on prolificacy records, and it represents genetic material from 11 British breeds (Hanrahan, 1987). The present Cambridge population has a litter size of about 2.8 for mature ewes, and up to 8 lambs/litter have been recorded; however, flock numbers are indeed small because of the level of supervision required to ensure neonatal survival and the poor carcass conformation with low returns. If prolific breeds are available, and the adaptability, performance, and product quality of the cross of local and prolific breeds giving the desired litter size are acceptable, it is the method of choice (Bradford, 1985). The reproductive performance in Finncross ewes under range conditions can be superior to purebreds in net reproductive rate and weight of lamb weaned over a period of several years (Ercanbrack and Knight, 1985).

The lifetime production efficiency of different crossbred ewes maintained on irrigated or dryland hill pastures in Oregon for 4 or 5 years of production has been examined (Saoud and Hohenboken, 1984). It is clear that the management system under which production occurs and the choice of breeds adapted both to management and to the physical conditions of the environment affect lifetime productivity. However, not all countries allow the importation of prolific breeds, and some prolific breeds lack some important traits for certain environments. For example, crosses carrying 50% Finn inheritance are unusually susceptible to pneumonia, have a high attrition rate, and tend to show summer anestrus characteristic of the Finn parent. The fleece and carcass traits may also limit their usefulness where there are stringent market requirements.

Crossbreeding programs using two maternal trait breeds (at least one of which is a prolific breed) to create an F1 dam line breed have been used extensively. These F1 breeds exhibit heterosis and tend to be superior to the average of their parents productively. These ewes, in a crossbreeding program, would be bred to a sire trait breed, and all offspring from this mating would be marketed for meat. This method of quickly improving the genetics of the flock is gaining in popularity to the point that some producers are creating enterprises out the production of superior F1 ewe replacements for sale to commercial flocks. A notable example of an F1 sheep is the Scottish Mule, which is a cross between the Blueface Leicester and the Scottish Blackface that forms the basis of lowground flocks in the United Kingdom. Finnish Landrace sheep are frequently used in crossbreeding programs to increase prolificacy. Many synthetic breeds stressing maternal traits such as prolificacy have been created in the last two decades through a multiway crossbreeding program and heavy phenotypic selection. Examples are the Arcott in Canada and Polpay in the United States, where litter size ranges from 2 to 2.8.

The second method is the use of major genes, such as the Booroola. The Booroola gene for high ovulation rate has stimulated much interest in the potential for increasing prolificacy. The Booroola merino is a highly prolific strain of sheep developed initially by two sheep breeders (Piper and Bindon, 1985). With a mean ovulation rate in 1982 of 4.2 (range of 1 to 10) and corresponding mean litter size of 2.5 (range of 1 to 7), the reproduction rate of the Booroola is different from that of any other merino and ranks among the most prolific breeds of sheep in the world (Piper and Bindon, 1985). The mean litter size of ewes heterozygous for the gene is approximately 1.0 lamb higher than in noncarrier ewes. The reproductive performance of a Booroola flock therefore depends on the proportion of the flock carrying the gene. Through repeated crossbreeding and heavy selection for prolificacy, the Booroola gene has been incorporated into other breeds (e.g., Dorset). Crossbred prolific ewes are bred back to the desired breed for several generations until the crossbreed has the phenotype of the selected breed while still carrying the Booroola gene.

The third method is selection within an adapted population. Selection requires recording in at least a nucleus flock. This method avoids the need for abrupt changes in inputs, such as supplemental feed and labor at lambing, and avoids abrupt changes in the product marketed. The factors favoring selection are lack of availability of prolific breeds or major prolificacy genes, and environmental or market requirements that make the prolific breeds or their crosses, or individuals carrying major genes for prolificacy, inferior to local breeds in total performance (Bradford, 1985).

Sheep meat production is dominated by two factors. First, there are the biological and agricultural considerations of resource use, in particular the efficiency with which feed is converted into lean meat. Second, there are marketing considerations, in particular the ability of sheep producers to adapt output to conform more closely with changing market demand. Progress in both factors is needed if sheep meat is to continue as an important component of the diet. Consumption of mutton and lamb in Britain has fallen from about 11 kg/person annually in the 1940s to about 7 kg/person annually in 1996.

Meat purchasers in attitude surveys have shown that they believe lamb lacks versatility and is too fatty and wasteful. Therefore the carcass is central to the various activities on which the improvement of meat is based. Carcass quality provides the primary measure of output and is a key selection criterion for genetic improvement (Kempster, 1983). Defined in terms of consumer requirements, the selection objectives for improved carcass quality would be for maximum lean, minimum bone, and optimum levels of fat. Most of the variation in body composition in live animals is associated with differences in the amount of fat in the body. As an animal increases in live weight or degree of maturity, the weight and proportion of fat in the body and carcass generally increase, with a reduction in the proportion of lean tissue. Thus carcasses with a higher proportion of lean could be produced without recourse to genetic improvement simply by slaughtering lambs at lighter weights (Simm, 1987). When breeds of different mature sizes are compared at the same live weight, the larger breeds generally grow faster and contain less fat and more protein and bone in the body and carcass than breeds of small mature size.

Genetic variation within and among breeds for growth and carcass composition indicates that breed substitution, crossbreeding, and selection within a breed can increase the percentage of lean in the carcass (Glimp and Snowder, 1989). Selection for rate of gain should improve the lean-to-fat ratio at a constant weight. Leaner carcasses of a given weight could be produced from a given production system by switching to a breed of larger mature size, other factors being equal. The genetic improvement of terminal sire breeds offers a permanent, cumulative, and relatively inexpensive method of improving the carcass composition of crossbred lambs. The carcass composition of lambs slaughtered at a given live weight may be improved by using a terminal sire of higher mature weight than that currently being

used. This may be achieved by breed substitution or within-breed selection. Further improvements may be possible by selecting for slower rates of maturation in fatness and for reduced fat content at maturity (Simm, 1987). The formation of new breeds to be used in breeding programs to improve carcass quality provides new opportunities to produce lean, tasty, well-presented lamb that sells at a premium (Fell, 1987). The Texel breed is gaining in popularity for this purpose. The selection of rams for leanness, measured ultrasonically and corrected for live weight, should increase lean percentage without increasing body size.

With regard to wool, most fleece characteristics are highly heritable, so improvements in weight and quality can be made through selective breeding. Considerable knowledge about the biology of wool production is available, but the way in which it is applied depends on the farming system. The factors that affect wool production include the level of nutrition, season of the year, physiological state of the animal (during pregnancy and lactation wool growth is depressed), and sex (entire males produce more than castrates, which produce more than females) (Doney, 1983). Only in low-cost extensive systems with low capital and labor inputs, such as in Australia, is it economical to produce wool as a primary product. In Britain, wool is a by-product of intensive lamb production for meat, and high meat prices and subsidies mean that wool accounted for less than 10% of the income of sheep flocks in 1986 (Ryder, 1987), and continues to fall to below 5% (MLC Yearbook, 1997). The major objectives of merino wool producers in Australia are a heavy, clean fleece weight, a specified mean fiber diameter, and whiteness. The merino is virtually the only breed in which it is economically viable to apply selective breeding solely to wool characteristics. Improvement programs for the specialized wool-producing breeds continue to aim to increase clean wool production while maintaining average fiber diameter. This requires the use of fleece measurement laboratories to determine yield and average fiber diameter of the ram replacements and ewes (McGuirk, 1983). Up until recently, it was generally accepted by research and extension workers that recommended breeding programs for improving wool production in the merino have been largely ignored by the merino industry.

Group breeding schemes have been developed in some countries to enable several small-scale breeders to combine into an effective breeding operation involving the screening of large numbers of females for use in a nucleus flock (Owen, 1987a). It is an efficient means by which native sheep flocks may be screened for superior females, and a vehicle for the efficient incorporation of foreign genetic material into adapted sheep breeds. Group breeding schemes commonly involve the cooperative action of 10 to 15 breeders who individually may possess only relatively small flocks. The most common form involves the initial screening of the female population in the members' flocks to establish a nucleus. This allows a two-way flow of genetic material between the member flocks and the nucleus. Breeding rams are transferred from the nucleus flock to the member flocks and, by continuous systematic screening of females in the member flocks, the nucleus is augmented.

Initially, ewes are donated to the nucleus flock, which is the property of the cooperative group of breeder members. In early December every year each member delivers to the nucleus his or her top-ranking 3-year-old ewe, as judged by the Meat and Livestock Commission index. This ewe, in lamb to a breeding in the member's own flock, remains on loan in the nucleus until she has lambed and the lambs are weaned. The ewe is then returned, and the lambs become the property of the cooperative group. Members are entitled to receive a yearling breeding ram from the nucleus for their own use. Replacements for the nucleus are selected on the basis of an index that is mainly weighted on prolificacy and ewe milking ability. Over a period of 5 years in the Lleyn sheep scheme in Wales, a high level of performance has been achieved in relation to ewe body size, lamb survival, and ewe-rearing ability (Owen, 1987a).

The major obstacle to the efficient improvement of sheep breeds is the difficulty of making accurate measurements on any but a tiny fraction of the population represented by any breed. The activities of many group breeding schemes, which rely on the intensive screening of base populations, are hindered by the difficulty of intensive recording, particularly for traits such as milk production (Owen, 1987a). The milk-producing ability in ewes can be measured by recording the milk yield on one day shortly after the lambs are weaned, at approximately 2 months of age. This allows the ewes in the flock to be ranked according to milk yield. A similar procedure can be used in the selection of rams. The ram lambs are presented for testing at weaning, and the lambs in any one flock are all weighed on the same day, with selection based on the ranking of lambs according to body weight. Lambs born to 2-year-old ewes, and those born early or late in the season, are separately identified by a paint mark so that selection does not unfairly discriminate against younger lambs and those with immature dams. Selected ram lambs then participate in a central performance test on winter grazing, ending at approximately 13 months of age (Owen, 1987b).

BASIC FLOCK HEALTH MANAGEMENT AND PRODUCTIVITY PROGRAM

A basic sample health program for the commercial breeding flock is presented here. It is based on the application of the practical and economical management strategies that can lead to the optimum levels of reproductive performance and lamb survival and to effective and cost-effective control of major diseases such as internal parasites, blowfly strike, clostridial infections, and footrot. To do this and still maintain maximum cost-effectiveness requires special care in avoiding overcapitalization and excessive use of labor in an effort to provide for all emergencies. This would be contrary to one of the principal needs of the sheep industry, which is to reduce the intensity of the permanent labor force employed and to cater to the peak needs for shearing, drenching, lambing, and other health and production tasks by the use of contract labor. It should be possible to provide for a health service by using, and even organizing and providing, such contract labor as part of the service. This consideration is of most importance to large flocks. In smaller flocks the profitable use of what is in effect a potential oversupply of labor may include the development of additional health maintenance techniques.

It would be unwise to commence a flock health program without experience and expertise in the control of the diseases that are the principal targets of the program and without the back-up services of labor and laboratory to support these activities. It is a job for experienced professionals, who must be paid professional standard rates. The program must be financially self-supporting (Quinlivan, 1981).

General Outline

The basis of a sheep flock health and production management program is the frequent and repeated encouragement of the farmer to adopt the recommended procedures that are essential to the maintenance of health, production, and welfare. Sheep producers can be encouraged to consider and adopt the veterinarian's recommendations by the develop-

ment of a client-veterinarian relationship that is directed toward the health and production of the flock. The relationship is fostered through regular contacts, which are essential to the overall strategy of the program. These include the following:

1. An initial farm profile to ensure that the farmer's objectives are understood. The primary objective is usually maximum profitability. Additional information must be obtained on the resources of the land, water, animals, labor, and money available to the enterprise. Discussion of the major problems should be combined with preliminary arrangements made for the data collection system. An analysis of the data of the previous 1 or 2 years is a great help in defining productivity and problems.
2. A system of timely checks and reminders adapted to the needs of each farm and sent by mail at times appropriate to the expected occurrence of the problem. For example, the farmer is advised to vaccinate now against enterotoxemia or to drench now for liver fluke or nematodiriasis.
3. Periodic solicitation from the farmer of data on performance in production and health maintenance tasks. This information is used to determine whether production targets are being achieved and whether recommended disease control procedures are being carried out. Failure to perform elicits a specific reminder of the need to do so.
4. A system of regular visits by the veterinarian, usually three or four each year, to carry out physical work and to discuss past performance and future recommendations. This personal contact is vital to provide for discussion about the value of the program.
5. An annual discussion by a small group of farmers (15 to 20 is a good number) on additions, deletions, and modifications of the program or its recommended techniques and targets to provide an opportunity for community discussion on difficulties encountered in achieving objectives.
6. Concentration on key issues, those that cause a lot of wastage in the flock, those that can be controlled with little expenditure, and those that are highly profitable. In most sheep-raising areas the same problems have the top priorities. These include reproductive efficiency, neonatal deaths, the need for genetic improvement, culling rate based on objective standardized measurement of body weight gains and fleece quality and yield, better management of pastures and their best use, including selective supplementary feeding, attainment of maiden ewes to optimum breeding weight at first mating, optimum BCS of adult ewes, feed levels at the end of pregnancy and early lactation, and restraint of the prevalence of infectious and other diseases to a level consonant with optimum profitability.

Programmed Visits

It is desirable to arrange two to five visits to each farm each year. If the major disease problems are identifiable, it is possible to arrange the visits at critical times in the proposed disease control programs including vaccination, foot paring and foot bathing, jetting for blowfly, lamb marking (docking and castration), and dipping for lice and ked infestations. A recommended program of visits is shown in Box 16-20 and Table 16-8.

Visits During Lambing

Visits during lambing time are of critical importance to ascertain how successfully the flock health plan is operating with particular reference to late gestation nutrition. It is essential that a large number (100 lambs or greater) of newborn lambs are weighed and these data analyzed with respect to litter size and dam parity. Blood samples should be collected from a representative number of lambs and total plasma protein concentration determined after centrifugation with a handheld refractometer. Plasma glucose concentration can be determined accurately with human test kits. These analyses are cheap and easy to perform on the farm and provide invaluable information that can be utilized immediately to reinforce aspects of management. These data can be compared with previous years to indicate trends. A large sample of lambed ewes should be condition scored and these data compared with values at breeding time and during mid-late gestation, thereby permitting assessment of nutrition throughout the entire gestation period. The experienced veterinarian will also detect early signs of disease problems, such as the first few cases of watery mouth disease

BOX 16-20

Farm Visits

PREBREEDING FARM VISIT
This is done 6 weeks before the beginning of the breeding season. The body condition scores of rams and ewes are determined and rations adjusted accordingly. Rams are examined for breeding soundness. Also, the ram-to-ewe breeding ratio, length of breeding season, advantages of pregnancy diagnosis, abortion control, clostridial vaccination program, and the previous year's health and production performance data can be discussed and reviewed.

MIDGESTATION FARM VISIT
This is done 7 weeks after the rams are removed. Pregnancy determination is carried out by real-time ultrasound examination. The ewes are scored for body condition and sorted according to the score and number of fetuses, and rations are adjusted accordingly. The breeding performance is reviewed.

PRELAMBING FARM VISIT
Facilities and supplies are examined for lambing, including the protocol for sick lambs, disease prevention measures for lambs such as vaccinations, storage of bovine colostrum or other supplements, and dipping of navels with iodine. Evaluation of the ration is of critical importance because of the major influence of late gestation nutrition on lamb birth weight and perinatal mortality in prolific flocks. The ration can be altered with respect to dietary current energy supply as outlined by Russel.* Collection of blood samples from a representative number of ewes and determination of the group mean serum 3-OH butyrate concentration form the basis of flock advisory visits in U.K. flocks where a lambing rate of 200% or greater is expected.† Any thin ewes detected at this time are separated into groups and the ration adjusted accordingly to ensure no further loss. Correct nutrition during late gestation is essential to ensure that ewes respond to the various vaccination regimens administered at this crucial time. Administration of a large amount of antigen to a debilitated ewe will not lead to adequate accumulation of protective immunoglobulin in the colostrum; rather such action may precipitate disease, including ovine pregnancy toxemia.

*Russel AJF: *In Pract* 7:23-28, 1985.
†Scott PR: *Proc Sheep Vet Soc* 13:110-112, 1988.

TABLE 16-8

Herd Health Program for Indoor March Lambing in a Temperature Climate

Reproductive Cycle Event	Month	Flock Health Visits	Body Condition Score (BCS)	Nutrition	Adults Management	Adult Disease Control	Lamb Management	Lamb Disease Control
	August	Visit 1, mid-August: Do rams breeding soundness examination, BCS, and *Brucella ovis* serology; advise on flushing nutrition, ram:ewe ratio, estrus synchronization, ram effect	Rams, 3.5-4.0	Increase ration to breeding rams mid-August	Cull unsuitable rams		Sell grass-fed lambs as they reach appropriate weight	Predator watch, monitor fecal egg count (FEC)
Mid-September: Teaser rams in	September		Ewes, 3.0-3.5	Increase ration to breeding ewes mid-September; sort thin ewes and feed extra	Ewes: check teeth and udder, cull unsuitable ewes, analyze store forages and formulate rations for all ages and production groups for year	Vaccinate for abortion diseases (*Chlamydia, Campylobacter*)		
October 5: rams in marking harnesses, change color every 14 days	October			Maintain ration until 3 weeks after rams removed (i.e., end of November)		Worm adults once housed with larvicidal drug, late November typically		
November 10: rams out, teaser rams in with marking harnesses	November							

Continued

TABLE 16-8—cont'd

Herd Health Program for Indoor March Lambing in a Temperature Climate—cont'd

Reproductive Cycle Event	Month	Flock Health Visits	Body Condition Score (BCS)	Nutrition	Adults Management	Adult Disease Control	Lamb Management	Lamb Disease Control
December 1: teaser rams out	December	Visit 2, late December: Do pregnancy checks and ewe BCS; advise on nutrition and sorting, vaccination, abortion	Ewes, 3.0-3.5 (sort ewes on BCS and no. of fetuses)	Maintenance ration for fetal and placental growth; late December—increase ration to thin ewes and ewes carrying multiples		Watch for abortions, submit fetuses, placentae for postmortem, contact vet for serology		
Mid-January: last trimester of gestation	January				Cull open ewes or move to next breeding group (accelerated lambing)			
	February	Visit 3, mid-February: do BCS on random ewes; advise on lambing facilities, supplies for preventive treatments		Increase ration to ewes with singles; watch for thin ewes	February 1: crutch or shear ewes and trim feet, sort ewes by due date or udder fill for closer observation	February 1: vaccinate ewes for clostridial diseases, watch for pregnancy toxemia, etc.		
March 1: lambing begins	March	Optional visit, midlambing, if neonatal mortality has been a problem in the past	Ewes, 3.0-3.5	Sort ewes by BCS and litter number and feed accordingly	As lamb: place in claiming pens (24-48 hr) strip teat plugs; check for adequate colostrum, mastitis	Watch for mastitis, dystocia, mismothering, indurative mastitis	At birth: claiming pens, dip navels; week 1—Tail-dock, castrate, watch nursing, save for postmortem stillborn and dead lambs	0.25 ml vitamin E-selenium injection at birth; tetanus antitoxin/Orf vaccination, as necessary, appropriate therapy hypothermic lambs; post-mortem dead lambs

Mid-April: Lambing finished	April					Indoors: optional worming after lambing complete before turning out to pasture		Housed lambs: coccidiostat in feed, watch for urolithiasis; pastured lambs: may need coccidiostat as well
Mid-May: lambs ready for weaning depending on management type	May	Visit 4, mid-May: review performance of past year and set goals for next year	Ewes, 2.0-2.5	Accelerated lambing: must have ewes weaned at BCS of 3.0	Weaning: check ewes for mastitis, cull based on reproductive and lamb performance	Worming: 3 weeks and 6-8 weeks after turned on pasture with larvicidal drug; optional—dry cow mastitis ointment at weaning (if high prevalence of mastitis)	Weaning: indoors—remove ewes from lambs; pasture wean onto safe pasture	Worming: pastured lambs only, wean at same time as adults
	June			At weaning decrease ration (no grain) so that slow increase to BCS of 3.5	Select teaser rams and vasectomize; foot trim and footrot treatment, as necessary		Select replacements based on performance; sell grain-fed lambs late May, early June	Vaccinate for clostridial diseases at 3 and 4 months; worm up to once/month on pasture
	July					Check fecal egg count in late July, worm if high		Predator watch on pasture

For lambing at other months of year, adjust reproductive cycle events.

(endotoxemia), polyarthritis, hepatic necrobacillosis, and omphalophlebitis-peritonitis not yet noted by the farmer. A visit at this time allows necropsies to be undertaken on a representative number of lambs. This farm visit should be undertaken about 1 week after the start of the lambing period, since many problems do not arise until one third to one half of the ewes have lambed.

Postlambing Farm Visit. The lambs are examined for performance, such as average daily gain, and for evidence of coccidiosis and internal parasites. The lamb weaning program is discussed, performance parameters reviewed for the past season, and goals set for the next season. Ewes are checked for mastitis and ewes selected for culling. In addition, when seasonally appropriate, the efficacy of parasite control (e.g., late summer), footrot control, and other flock-specific disease control programs (e.g., maedi-visna, abortion) should be reviewed.

Timing of Visits

Periodic visits by the supervising veterinarian to sheep farms using flock health programs need careful timing. The schedule needs to take into account other managerial activities on the farm so that visits do not conflict with them unnecessarily but take place when sheep would ordinarily be handled for other purposes. Whenever possible, the visits should not be simply for looking and advising. There is also an advantage in having the visits synchronized with a relevant farm activity, such as drenching or marking, which could be useful to observe.

Data Collection and Storage

Management Data

It is necessary to have some method of recording management details in order to provide information on the quality of animal management and the intensity with which the program's recommendations are applied. It is therefore necessary to record details of sheep groups and their numbers, age, and genetic composition without necessarily identifying each sheep. Also, management details such as supplementary feeding, BCS, fleece weights, numbers and dates of sales of sheep, and prices received for products all need to be recorded.

The best arrangement is to set up groups of sheep on an age basis and to retain them in these groups for as long as possible. The group is identified by ear marks or ear tag, and this is usually sufficient for the maintenance of adequate records. The difficulty arises when sheep from a number of groups are commingled. It is then necessary to identify a new group composed of the residues of a number of groups, each of which may have a different history.

An alternative or supplementary method is to group ewes on the basis of their breeding dates, so that they are all likely to be lambing at about the same time. As the ewes lamb, they are drifted off until the group is sufficiently large; a new group is then formed. The other method is to identify the ewes bred by using a mating indicator harness on the ram and removing the ewes from the original group as they are marked. Both techniques are inclined to confuse the original groups and their histories.

The basic requirements for collecting all information, managerial and disease related, is a structured diary with tear-off sheets that are filled in and sent to the veterinarian on a regular basis. This permits the record keeping to be monitored constantly and the data to be stored at a constant rate during the year. Each interim report should include a statement on the following:

- Climate, feed supply, and rainfall
- Management procedures, including sales, births, data on rams in and rams out, supplementary feeding, shearing, crutching, marking of lambs
- Preventive veterinary procedures (e.g., drenching for worms or flukes, jetting, dipping, vaccinations, examination of rams for breeding soundness)
- Deaths and illnesses, postmortem examinations conducted

A second document considered essential is the annual management profile, which records in detail the resources, management, and objectives for the farm. By these means, significant changes in these activities or aspirations are recorded.

If a cash flow report is to be provided, there needs to be additional information on prices obtained for wool and stock and prices paid for feed and other supplies.

No details on the types of forms used in the programs just mentioned are provided here because they are specific to the particular area, methods of husbandry, and economic status of the animal industry in question.

Because the amount of data is relatively small, there usually being only a few groups of sheep on each farm, the data can be handled manually. Manual handling is already necessary for much of the data because it is qualitative rather than quantitative information (e.g., the state of the pastures). Comparisons of results between farms and before and after on individual farms, including partial budget estimations of financial status, require a combination of descriptive, numerical, and financial data.

Health Data

Information on health matters, including deaths, necropsy results, illnesses, treatments, and prophylactic techniques, is recorded in the diary provided, and copies are forwarded periodically to the data laboratory. More detailed reports of work performed by veterinarians or the diagnostic laboratory are supplied to the data laboratory, and the information is coded and stored.

Ideally, a necropsy examination should be carried out on each sheep that dies, but in a pastoral economy that is run on extensive lines, it is impossible to do this. The best that can be done is to encourage the producer to submit as many cases as possible for necropsy. If outbreaks of disease occur, these should be investigated and appropriate measures taken.

Analysis of Data: Reporting to Farmers

The number of reports provided to the farmer each year depends on the amount of stimulation required by the farmer and the additional costs raised by each additional report. It is usual to supply a report after each visit—that is, two or four per year. One of these is an annual report containing a review of the entire performance of the flock for the past year. The others are interim reports covering the period since the previous report.

Annual Report

The annual report should include a report on all the indexes that have been monitored, including those relating to health and those dealing with production. It would also be simple to predict sheep numbers for each of the succeeding months based on numbers of ewes mated, breeding date, and anticipated fertility index. This would permit forward planning of feed supplies. Also included should be a list of the activities carried out in each group, together with its record of production.

In terms of timing, the logical occasion for an annual report is when lambs are weaned or marketed and the analysis of reproductive and growth performance is completed; thus, July 1 or January 1 is suitable, depending on whether the lambing is in the spring or autumn.

Interim Reports

Interim reports should be supplied after the prebreeding visit, the visit during late gestation, and the visit during lambing time. These reports are supplemented by error messages when examination of the records indicates that a recommended procedure has not been carried out, and reminders are sent out to advise farmers of specific tasks that should be carried out at specific times.

Interfarm Comparison

If an annual meeting of a study group of farmers is arranged, it is common practice to discuss a comparison among farms so that farmers know how their performance rates with others. Identities are masked by a code number and performance in each of the indexes is listed. There may be good reasons for a farmer not to even attempt to achieve one or more targets, and these often serve as good points around which to arrange a discussion.

Manual or Computer Analysis of Data

If the expense of the computer program can be borne, it is preferable because it is so error free, consistent, and successful at carrying out repetitious bookkeeping and examination of records. In comparison with dairy cattle, there are relatively few incidents to record, and a manual data processing system is adequate if there are only a few flocks. If there are a large number of sheep or if many additional procedures are used, however—such as individual identification, weighings, and use of a crayon marking breeding harness—the manipulation of record cards becomes tiresome. Many sheep producers have now written their own spreadsheets to track animals and produce action lists. These programs can be incorporated with Record of Performance data to analyze data and create reports of reproductive performance of the last breeding period.

Costs and Benefits of Sheep Health Management

Costs

The costs of a sheep flock health and production management program consist of the professional veterinary fees and the costs of animal health products such as vaccines, anthelmintics, insecticides, antimicrobials, and other drugs used in sheep production. Veterinary practices have had a major impact in the sheep industry through the professional advice they offer along with the provision of animal health products. The cost-effectiveness of these programs in the hands of experienced veterinarians who are advising average sheep producers is excellent. There are always a few farmers whose management and disease control is so good that the program offers them little financial gain, but they are recognizable early if a retrospective analysis of data is done at the time of the original farm profile. Some of these farmers decide not to continue, but most do in order to have insurance against error.

The professional fees for visits to the flock and for health management consultation and advice are best based on an hourly fee. However, some producers prefer to pay on a per breeding ewe-per year basis for health management services provided by the veterinarian. In addition to the time spent on the farm, the other tasks include arrangement of laboratory tests, answering of telephone calls for advice, analysis of data (often by computer), discussions with and arranging visits by other consultants, and preparation of reports, which are usually done in the veterinarian's office.

The time spent on the farm varies with the numbers of animals and problems to be assessed and corrected. A commercial flock of 2000 ewes would require at least four 3-hour farm visits annually. At $70/hr (U.S.), the costs of the on-farm professional services are about $840, or about 42 cents/ewe annually. For each farm visit, an additional 1 or 2 hours is necessary to analyze records, prepare reports, and make recommendations to the producer. This increases the annual professional fee to 56 to 70 cents/ewe. Transportation costs to the farm and the costs of animal health products such as anthelmintics, vaccines, antibiotics, and insecticides increase the total annual costs to $1.00 to $1.50/ewe.

In the United Kingdom flock size is generally smaller (averaging 500 ewes) but flocks over 2000 ewes are not uncommon. Increasingly, flock health schemes have become part of a welfare-based marketing exercise undertaken by large supermarket chains. Unfortunately, these health schemes are primarily concerned with food safety and accurate recording of treatments and sheep movements rather than with the major objectives of sheep welfare and productivity. Farm inspections are undertaken annually by lay people and not veterinarians and have not been well received by sheep producers. Standards demanded by membership at present can be achieved readily by almost every farmer, and a radical review of such schemes is overdue, but it would appear that the veterinary profession is unwilling to meet these challenges. Consequently, sheep health and production represents only a small proportion of food animal services in rural areas. The potential for veterinary services in the United Kingdom can be readily determined after reference to performance data produced by the industry. While the top third of lowland spring lambing flocks rear 160 lambs/100 ewes mated, the annual ewe mortality rate was 5% with 4% barren; lambs losses totalled 17/100 ewes mated (MLC Yearbook, 1997). These data relate to the top flocks and are unlikely to be representative of the majority of sheep producers; indeed perinatal lamb mortality rates in excess of 15% are widely quoted (Whitelaw, 1976; Eales et al, 1983; Barlow et al, 1987; Hindson and Winter, 1990) with the annual ewe mortality rate between 6% to 8%. These losses must be considered in context and are all the more disappointing because most flocks lamb indoors with 24-hour supervision, availability of highly efficacious vaccines against chlamydial abortion and toxoplasmosis, absence of predators, and routine administration of oral antibiotics to all lambs within 15 minutes of life (Eales, 1985).

Economic Benefits to the Sheep Producer

If the cost-effectiveness of the flock health program is to be assessed, the gross and net incomes must be determined. Failing this, the income can be estimated on the basis of yield multiplied by value. For wool, the total wool sold comes from bale weights and the yield per sheep from the bale weight divided by the number of sheep shorn. This figure is available from the shearing shed cut-out figures. The quality of wool can be determined by access to the objective measurements if they are used as a basis for the sale of the wool.

Body weights are harder to obtain, unless the lambs, hoggets, and wethers are sold to abattoirs on a weight basis or are weighed by the abattoir for its own purposes. The use of scales on the farm might be unreliable because of variations in gut fill that occur during the day, making the assessment of carcass weight from live weight a haphazard arrangement.

In many countries lambs are not only weighed but are also graded on conformation and fatness by the use of a grid classification at the slaughter plant (MLC Yearbook, 1997), providing the producer with accurate and reliable data on

which to base management decisions. Seasonal variation, indeed marked weekly fluctuations, in price may influence income, but most producers market lambs over a period of months; such fluctuations even out in the final financial assessment.

The publication of reference performance data (MLC Yearbooks) affords veterinarians and other livestock advisors accurate yardsticks to measure their clients' performance. One criticism is that these commercial flocks do not provide sufficiently high targets, and it can prove difficult to motivate those flockowners who exceed the "top third of producers." However, these data produced under commercial pressures are useful in the formulation of a flock health plan and should be readily consulted.

CONTROL OF OTHER ECONOMICALLY IMPORTANT DISEASES

The following diseases were chosen to be listed out of the large number that affect sheep because they are universally present, cause significant wastage, and must be included in a basic program. These are gastrointestinal helminthiasis, blowfly strike, clostridial diseases, footrot, and maedi-visna. They are only reviewed here because they are detailed in most textbooks of farm animal medicine (Radostits et al, 1994).

Gastrointestinal Helminthiasis

Gastrointestinal helminthiasis, especially that caused by nematodes, is a major health and production problem in sheep flocks and accounts for large economic losses. Economic loss results from clinical disease, suboptimum performance because of subclinical infection, and all the costs associated with the use of anthelmintics. Clinical disease can result in deaths, and subclinical disease reduces the growth rate of youngstock and reduces wool production. Helminth infections in sheep can also cause a reduction in birth weight of lambs, reduced fertility of ewes, and a reduced percentage of ewes rearing lambs to weaning. The use of anthelmintics without due regard for the epidemiological characteristics of the nematodes in a particular area is a major cause of economic loss. Furthermore, the development of anthelmintic resistance is also related to their use, and failure of anthelmintic effectiveness is a source of economic loss.

Principles of Control

Eradication of most helminth infections is not practical. Traditionally, most parasite control strategies were protective in orientation and were based almost entirely on the regular use of anthelmintics. The anthelmintics usually provided protection against serious clinical disease and mortality but frequently were not effective in preventing the exposure of animals to high levels of pasture infection. As a consequence, production losses still occurred because of reinfection in the interval between treatments. The principles of control of gastrointestinal helminthiasis in sheep are as follows:

1. Strategic, therapeutic, and prophylactic administration of anthelmintics.
2. Management techniques designed to prevent or limit contact between parasite and host (Brundson, 1980). The strategies include prevention of the buildup of dangerous numbers of larvae on pastures, and anticipation of the periods during which large numbers of larvae are likely to occur and removal of susceptible animals from heavily contaminated pastures before these periods. These aims can be achieved by using three interrelated approaches: grazing management, the use of anthelmintics, and dependence on the acquisition of immunity. The most efficient control requires the complete integration of all three facets (Brundson, 1980).

Much has been learned about the epidemiology of helminth disease in farm animals. This information can be used by the producer and veterinarian to develop the most effective and cost-effective strategies for the control of parasitic gastroenteritis in the sheep flock (Armour, 1980; Morley and Donald, 1980).

The most prevalent and important helminths in sheep are the trichostrongylids, *Haemonchus contortus, Teladorsagia circumcincta,* and *Trichostrongylus colubriformis.* These nematodes have a simple and direct life cycle. Eggs are passed in the feces, hatch, and develop through free-living L1, L2, and L3 stages within a week under optimum conditions. L3 is the infective stage, during which larvae migrate from the feces onto the herbage and are ingested by the grazing animal. After ingestion, they pass to the abomasum and intestines and develop into fourth-stage larvae within the glands lining the walls of these organs before emerging as egg-laying adult worms about 21 days after ingestion. Developing fourth-stage larvae cause damage to the lining of the abomasum and intestines, causing malabsorption, inappetence, unthriftiness, diarrhea, and anemia in the case of *Haemonchus* sp.

The helminths just described have developed adaptations to ensure transmission from one host generation to the next. These adaptations include hypobiosis and the periparturient rise in egg output by ewes, prolonged survival on eggs on pasture, and a long adult life span in some instances. Hypobiosis is a temporary but sometimes prolonged period of arrested development of the fourth stage of the larvae in the host. All the commonly occurring nematodes of sheep in North America are capable of hypobiosis, which occurs during the winter period. In the northern temperate United States, *H. contortus* overwinters almost exclusively in the hypobiotic state (Herd et al, 1984b). Maturation of the arrested larvae eventually occurs, which leads to an increase in the number of egg-laying worms; this in turn causes an increased fecal nematode egg output. In parturient ewes the increase in egg production may be marked; this is known as the "spring rise" or the periparturient rise in egg counts from 2 weeks before lambing until 8 weeks after lambing, regardless of the season (Herd et al, 1983). This sudden increase in egg production is the major source of pasture contamination early in the grazing season and is the prime source of infection for lambs. These lambs in turn can serve to augment pasture contamination, leading to heavy levels of pasture infectivity during late summer and fall (Gibbs, 1986).

Thus, under temperate conditions, the periparturient rise is a major source of contamination contributing to the summer peak of larvae on pasture. These larvae are mainly responsible for the first generation of worms that accumulate in lambs during the summer, because most of the larvae that overwinter disappear rapidly from the pasture during the early part of the summer before the lambs are grazing extensively.

The treatment of ewes in the spring early enough to remove arrested larvae has been highly successful in controlling the subsequent levels of parasitism in lambs. The strategic administration of anthelmintics to suppress the spring rise in egg production from ewes can reduce pasture contamination (Herd et al, 1984a). Prelambing treatments with levamisole or fenbendazole are effective in eliminating the hypobiotic stages of the worms and both the primary and secondary periparturient increases (Herd et al, 1983). Postlambing treatments may be too late to affect the periparturi-

ent rise. However, if the ewes lamb indoors, the anthelmintic can be given at lambing before they are turned out to grass.

It is now recognized that animals exposed to nematode infections develop immunity to the causal helminth. At the start of their second year at grass, yearling sheep have usually acquired an immunity to helminth infections. As a consequence, only a small proportion of the infective larvae that they ingest develops into adult worms and lay eggs, and those that do are probably expelled from the animal quickly. In the ewe there is a temporary relaxation of this immunity at the time of lambing, and during the course of early lactation this causes the periparturient spring rise in egg output. Because the development of immunity depends on exposure to infection, the application of anthelmintics may influence its development. The intensity and timing of anthelmintic administration must be arranged to effect acceptable control of the parasites and yet not depress the development of immunity (Gibson, 1980).

Sheep nematodes exhibit marked seasonal patterns of pasture infectivity. Sheep turned out to pasture in the spring in northern climates may be exposed to light infections from overwintered pasture L3 stages of *Teladosargia, Trichostrongylus,* and *Nematodirus* sp. (Smith and Fulton, 1989). By midsummer, sheep are commonly exposed to large numbers of second-generation L3 stages capable of causing disease. These infections originate from the maturation of the hypobiotic stages of the larvae that were present in the ewes and have now matured, and in part from the eggs shed by sheep infected early in the spring. The warm temperatures and rainfall of the summer provide ideal conditions for the explosive development of large numbers of infective L3 stages. These findings emphasize the need to attack first-generation helminths early in the year to prevent the escalation of second-generation worms in the summer months. The use of anthelmintics in late summer and fall, when the infectivity of the pasture is high, is usually ineffective over the long term because reinfection occurs quickly and the helminth load returns to pretreatment levels. For effective worm control, the timing of treatments must be related to the seasonal development of infective larvae on pasture.

Practical Control Strategies

The most important aspect of a program is education of the farmer regarding the principles behind parasite control. A survey of anthelmintic usage for sheep in New Zealand indicated that many farmers do not have an elementary understanding of the properties and limitations of anthelmintics (Brundson et al, 1983). Farmers may not fully realize the importance of dose rates and that most anthelmintics do not have a residual effect. This lack of knowledge is the collective failure of anthelmintic manufacturers, research workers, and veterinarians to communicate the appropriate information adequately to farmers (Brundson et al, 1983). Few farmers appear to have a clear idea of the purpose of prophylactic anthelmintic administration, which is to prevent contamination of pasture during epidemiologically important periods. They either treat youngstock regularly throughout the year as insurance against serious disease and to achieve peace of mind, or they treat protectively during the period of greatest risk or curatively after the appearance of ill thrift and/or onset of clinical disease. These methods are not cost-effective compared with the most cost-efficient method of integrated control, which requires forward planning of grazing management (Brundson et al, 1983). With a knowledge of the epidemiology of the helminths, a number of the following control strategies can be recommended.

Prelambing Treatment. A winter treatment of early-lambing ewes with levamisole or ivermectin at the time of housing eliminates arrested larvae and prevents maturation to adults and the periparturient rise (Herd, 1984, 1986). The treatment can be given any time around lambing, but it must be done before the ewes go out to spring pasture (Fig. 16-7). The major objective is to prevent ewes from contaminating spring pastures (McKellar et al, 1988). It is unlikely that many worm eggs shed within the barn before treatment develop to the infective L3 stage. Late-lambing ewes require a second treatment just before lambing if they have already grazed spring pasture contaminated with overwintered larvae. Both early- and late-lambing ewes that have been treated are best kept indoors or moved to clean pastures after treatment to avoid immediate infection. If pregnant ewes are housed from mid-pregnancy to lambing because of inclement weather, the use of levamisole during the last 10 weeks of pregnancy can improve the birth weight of lambs and increase the milk production of the ewes, thereby increasing the lambing percentage (Brown et al, 1984).

Administration of Anthelmintics and Movement to Safe Pastures. The movement of anthelmintic-treated sheep to a safe pasture extends the effectiveness of a single treatment and reduces reinfection. A safe pasture must not have been grazed by sheep for at least 3 months or more. Treatment removes the worm burden and protects a safe pasture from contamination. However, it must be remembered that some gastrointestinal ova and larvae can survive overwintering, and "safe pasture" is a relative concept. It is also important to note that, because of economic considerations, few producers can leave a pasture free of sheep for 3 months during the growing season unless alternated with cattle. This strategy requires some forward planning to secure the safe pastures and to make provisions for efficient use of the pasture after it becomes highly infective and cannot be grazed by susceptible sheep.

The production of safe pastures depends on the prevention of contamination during critical periods. Contamination is avoided by eliminating sheep grazing from certain areas of the farm for specified periods, which requires about 3 months or more. Contamination can also be reduced by dilution through the use of mixed grazing of sheep and cattle or alternate grazing. Alternate grazing of cattle and sheep also provides safe pastures because of the relative lack of cross infection between cattle and sheep. Pastures can be allowed to grow forage, which is then harvested for hay or silage. After harvesting, most of the previous year's overwintered larvae have died. Safe pastures can also be produced by the use of critical, strategic anthelmintic treatments when free-living development is minimal. The administration of anthelmintics during the dry summer period in Victoria, Australia, for example, produced safe grazing pastures for autumn and winter (Brundson, 1980). The weaning and treatment of lambs before grazing on clean pastures is also effective for the control of *H. contortus* because removal of the ewes as a source of contamination is effective in controlling hypobiosis (Tritschler et al, 1989).

The provision of ewes and their lambs with pastures relatively free of helminth infection (safe pastures) from lambing in spring until weaning is beneficial (Waller et al, 1987a; Fawcett and MacDonald, 1988). In southeastern Australia, ewes grazing safe pastures and drenched once before lambing produced more wool than did ewes on contaminated pastures (Waller et al, 1987b). An additional benefit was increased control of blowfly strike because of less fecal soiling of the breech in lambs.

Prophylactic Anthelmintic Administration in the Spring. This is given to sheep after they are turned out to spring pasture and become infected with the overwintered L3 stage on pasture. Treatments given at 3-week intervals starting 3 weeks after turnout usually kill newly ingested

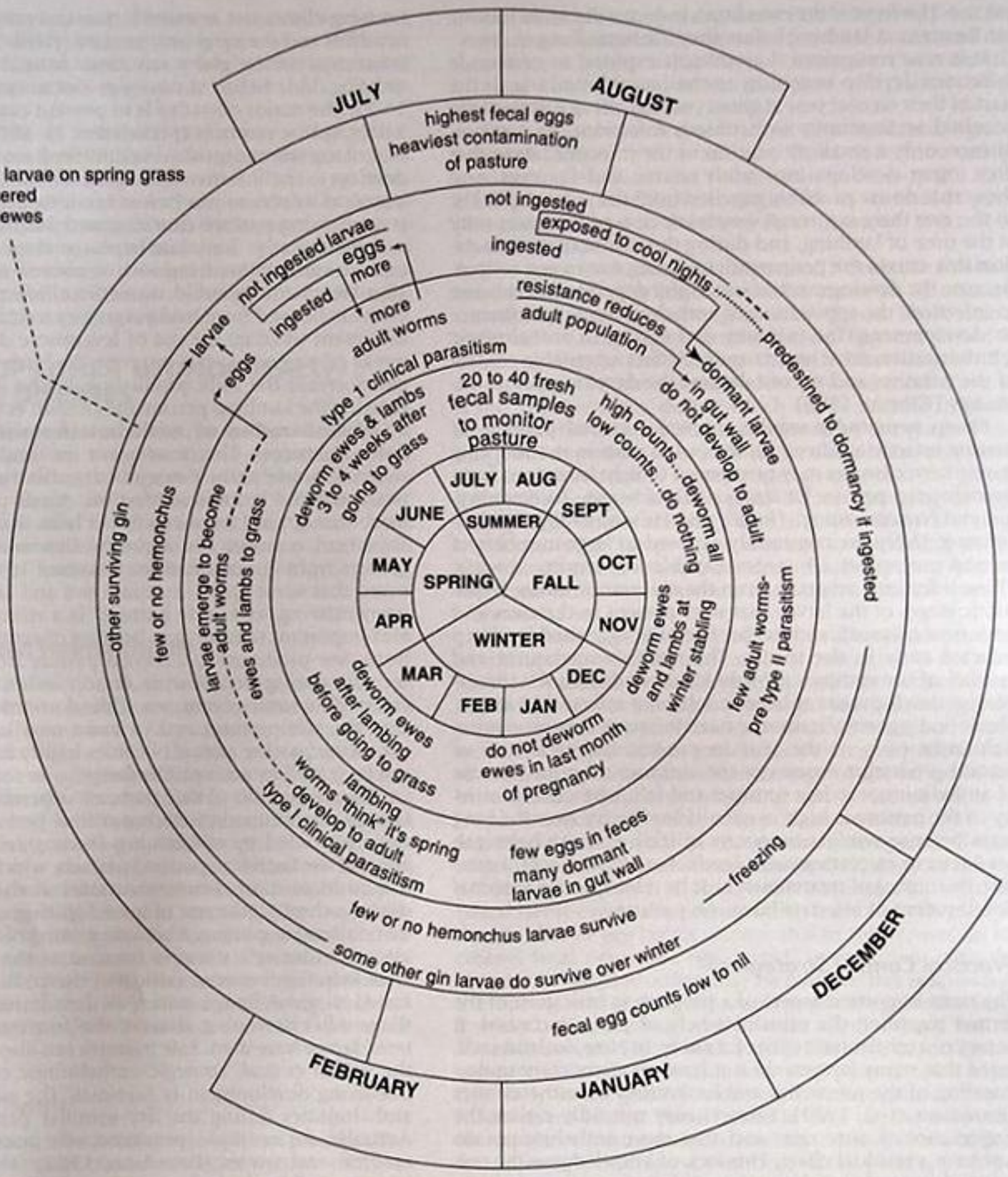

FIG. 16-7 Seasonal and monthly sheep deworming program. (Courtesy of JP Lautenslager.)

larvae before they mature and start contaminating pastures with large numbers of eggs. In the northern United States, four treatments at 3, 6, 9, and 12 weeks after spring turnout were just as effective as eight treatments at 3-week intervals in preventing the escalation of second-generation worms and achieving desirable weight gains (Herd, 1986). It is also important to give prophylactic treatments at no more than 3-week intervals; at monthly intervals, larvae ingested after treatment mature and pass eggs before the next treatment and cause pasture contamination. As temperatures increase in the summer, the remaining overwintered L3 stage larvae die off and there is relatively little new contamination with eggs (Herd, 1986).

Set-Stocking and Anthelmintic Administration. In many commercial flocks, lambing occurs on set-stocked permanent pastures contaminated with nematode eggs from sheep grazing in the previous autumn or winter. Set stocking is the practice of stocking a pasture with large numbers of animals for long periods of time. The pastures become heavily contaminated with infective larvae, and their numbers increase during wet seasons and decrease during the dry seasons. Anthelmintics are given frequently and regularly at times suggested by the epidemiological characteristics of the nematode; the objective is to maintain a low level of pasture contamination. Rotational grazing has been strongly recommended in the past but, on a practical basis, pastures cannot

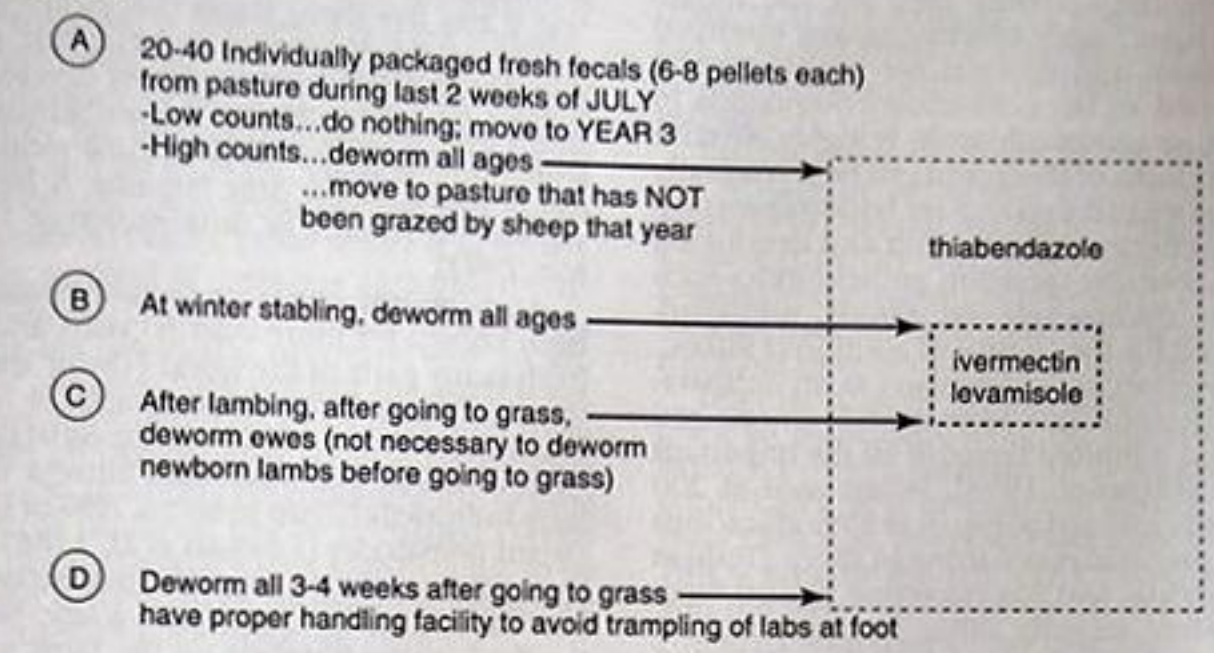

FIG. 16-8 Yearly sheep deworming program.

be spelled off until almost all larvae have died without damaging the pasture. For complete elimination of pasture infestation, an interval of 2 years between grazing is necessary but is not usually practical.

Clean grazing systems—which alternate cattle, sheep, and crops annually—have been described, but few farms have the correct ratios of livestock. Performance data of lambs reared on clean grazing systems are superior to those systems that attempt to control parasitism by chemoprophylaxis.

Choice and Use of Anthelmintics. The proper use of anthelmintics necessitates an understanding of the mode of action, the pharmacodynamics of the various drugs, and the factors that affect efficacy, because this information leads to the correct choice of the compound to be used in a particular circumstance. Arundel (1985) has pointed out that unfortunately, in practice, the compound is often selected without adequate consideration of the circumstances. Often, the choice of anthelmintic is made on the basis of the breadth of spectrum, narrow or broad, or price, without any effort being made to determine which parasites are present and causing the clinical condition or the effect of the routine use of broad-spectrum anthelmintics on the development of resistance.

A survey of the use of anthelmintics in New England indicated that sheep producers have a lack of awareness of the rationale for the use of anthelmintics (Tritschler et al, 1986). The administration of anthelmintics was commonly done when convenient and when other activities occurred, rather than with an epidemiological approach to the parasite. Only 27% of farms had a distinct drenching program for lambs, and less than 4% followed a grazing practice based on the control of the parasite. Producers were unaware of the side resistance (discussed later) among benzimidazoles in particular. About one third of producers had discontinued the use of an anthelmintic, most commonly thiabendazole, because they considered it to be ineffective. Excellent published material is available on the use of anthelmintics, their mode of action, the withholding periods to be used, and the problems of anthelmintic resistance (Gibson, 1980; Ministry of Agriculture, Fisheries and Food, 1984; Arundel, 1985).

The epidemiology of the major parasites of sheep is now well known for most areas, and the timing of treatments that can achieve maximum epidemiologic impact and minimum production losses has been determined (Fig. 16-8). If the best results are to be obtained, veterinarians and other advisers to the animal industries should understand the principles involved in the use of anthelmintics.

Broad-spectrum anthelmintics include the benzimidazoles and probenzimidazoles, the imidazothiazoles, the tetrahydropyrimidines, and the avermectins and milbemycins. Thiabendazole was the first of the benzimidazoles, followed by parbendazole, cambendazole, mebendazole, oxibendazole, fenbendazole, oxbendazole, and albendazole.

Most of the anthelmintics currently used are the broad-spectrum types, which are highly effective against intestinal nematodes. Thiophanate and febantel are probenzimidazoles that are converted to benzimidazole compounds in the body. Levamisole, an imidazothiazole, is highly effective against intestinal helminths of sheep and can be given orally or by injection. Morantel and pyrantel are tetrahydropyrimidines and are highly effective against adult and developing immature helminths. Narrow-spectrum anthelmintics such as the salicylanilides oxyclozanide, rafoxanide, nitroxynil, and brotianide are used for the control of adult liver flukes.

Ivermectin is an avermectin widely used as an antiparasitic agent. It is highly efficacious against adult worms and against developing and inhibited larvae of all the important nematodes of sheep (Marriner, 1986). When used at 200 μg/kg in experimentally infected sheep, it is 99% efficacious against the common nematodes occurring in sheep (Todd et al, 1985). It is not ovicidal and has no action against tapeworms and flukes. More recently other avermectins have been introduced, including abamectin, doramectin, and eprinomectin, and milbemycins such as milbemycin and moxidectin. In sheep, abomasal worms may be controlled for 5 weeks after moxidectin treatment (Bishop, 1998).

The following are several important factors influence the efficiency of anthelmintics used in sheep (Arundel, 1985).

Route of Administration and Dose. Most anthelmintics for sheep are given orally, and the operator must ensure that the drenching gun delivers the correct amount and that the animal swallows the product. Regular calibration of the drenching gun is recommended. Some products are given by injection. Producers may unintentionally underdose sheep, particularly adults, because they underestimate the body weight of the animals and because of variations in body weight within a group of sheep. Sheep must be weighed regularly and dosed on the basis of the heaviest in the group and not on the average body weight. It is important for the veterinarian to ensure that the producer understands the directions for use of the anthelmintic are fully understood.

Esophageal Groove Reflex. Some anthelmintics are more effective if delivered directly into the abomasum rather than the rumen; the reverse is also true.

Particle Size. Micronization provides greater surface area and leads to higher concentration in the fluids of the gastrointestinal tract, with more rapid absorption and greater effectiveness.

Anthelmintic Resistance To Nematodes. Anthelmintic resistance can be defined as a heritable change in the ability of individual parasites to survive the recommended therapeutic dose of an anthelmintic drug. Resistance is present when a greater frequency of individuals within a population is able to tolerate doses of a compound than in a normal population of the same species, and this resistance is heritable. Prichard et al (1980) and Waller (1986) have provided the following definitions of resistance. *Side resistance* exists if the resistance to a compound is the result of selection by another compound with a similar mode of action. Cross resistance resembles side resistance but involves compounds with different modes of action. *Multiple resistance* occurs when individuals are resistant to two or more different anthelmintic groups, either as a result of selection by each group independently or as a result of cross resistance. *Reversion* is a decrease in the frequency of resistant individuals in a population following removal of the selecting agent. *Counterselection* is reversion hastened by the use of an anthelmintic with a different mode of action to that which induced resistance. A synonymous, but less-favored term, is *back selection*. Selection pressure is determined not only by the dose of anthelmintic, but also by the proportion of the parasite population exposed to the drug. Selection pressure is high when anthelmintic treatment leaves few survivors and there are few, if any, free-living stages that escape exposure.

The establishment of anthelmintic resistance within a population follows a three-phase development. Initially the worms are susceptible to the anthelmintic, then heterozygous individuals gradually become more prevalent but clinical response to the drug remains. A homozygous resistant population follows as drug resistance is established (Jackson, 1993).

Anthelmintic resistance to gastrointestinal helminths has been known for more than 30 years and has been reported from many parts of the world (Taylor and Hunt, 1989). The literature on anthelmintic resistance in the United Kingdom (Taylor and Hunt, 1989) and in Australia (Hall, 1990) has been reviewed and discussed. Surveys in western Australia have indicated that up to about 70% of sheep flocks have resistant nematodes (Edwards et al, 1986). The factors related to resistance of one or more nematode genera to one or more anthelmintics include flock size, percentage of ewes in the flock, cattle numbers on the farm, main sheep production activity, grazing strategy, frequency of drenching, changes in the frequency of drenching, number of summer drenches, and the method of estimating dose rates (Edwards et al, 1986). Large-scale surveys of sheep farmers in Australia and New Zealand have revealed many misconceptions about the properties, limitations, and use of anthelmintics. Modern anthelmintics are safe and cheap, and originally they were effective. Nematode control programs often consisted merely of giving occasional anthelmintics according to traditional practices and beliefs, when sheep were yarded for some other reason, with little attention paid to the epidemiology of the parasites (Waller, 1986).

Frequent treatment at intervals close to the prepatent period of the parasite, such as monthly, is considered to be the most important factor in the development of a resistance problem. The most notable example is the resistance of *H. contortus*, which developed in chronological sequence to phenothiazine, the benzimidazoles and probenzimidazoles, and levamisole and morantel. In South Africa, strains of *H. contortus* have been identified that are resistant to the benzimidazoles, to the salicylanilides rafoxanide and clostanel, and to ivermectin (Taylor and Hunt, 1989). In Europe, resistance of sheep nematodes has been reported from several countries, including France, Germany, Holland, and Switzerland (Taylor and Hunt, 1989). Resistance to thiabendazole was seen in Australia in 1968 and is now known to be widespread in *H. contortus* almost worldwide (Cawthorne and Cheong, 1984). Because the benzimidazoles are related chemically, there is considerable cross resistance. Benzimidazole resistance in several gastrointestinal nematodes of sheep in New Zealand has now been reported (McKenna, 1989; West et al, 1989). The purchase and importation of sheep harboring resistant *Haemonchus* sp. may also be the explanation for the rapid appearance of anthelmintic resistance on one farm where previously the commonly used anthelmintics had been effective (West and Probert, 1989).

A diagnosis of anthelmintic resistance should not be made without good evidence. The most common cause of failure of parasitized sheep to thrive after treatment is the rapid reinfection that occurs when animals are placed, after treatment, on a heavily contaminated pasture. Another cause is an incorrect diagnosis when ill thrift is the result of nutritional inadequacies or other diseases. Tests for resistance include the egg count reduction test, in which there should be a reduction of more than 90% in the egg count if susceptible strains are present. The diagnostic value and interpretation of fecal egg counts in sheep have been evaluated (McKenna and Simpson, 1987). There is a good relationship between the egg count and the estimated flock worm burden

when 10 to 15 egg counts on randomly selected members are performed. The exception is during the late fall and winter months, when the larvae are in the hypobiotic state. A total worm count can also be done 10 days after routine treatment, followed by necropsy examination to determine which species remain and are resistant. There is good agreement between the fecal egg count reduction test and the reduction in worm numbers (Waller, 1986; Waller et al, 1990).

The most reliable method of assessing anthelmintic resistance is the experimental infection of groups of worm-free animals with third-stage larvae and treatment with an anthelmintic when the parasites have reached the adult stage. The animals are then slaughtered 10 to 14 days after treatment and their worm burden counted. By treating at different drug concentrations, an ED50 (the concentration of drug required to kill 50% of parasites) can be calculated (Taylor and Hunt, 1989). The selection of which anthelmintic to be used in the future may depend on an anthelmintic resistance test on the farm in question (Edwards et al, 1986).

If anthelmintic resistance is detected in a flock, a change to an unrelated anthelmintic group should be done (Taylor and Hunt, 1989). More importantly, the parasite control program that has been used should be investigated, and, if necessary and possible, the anthelmintics in use should be changed to ones less likely to select for resistance. Narrow-spectrum anthelmintics to replace broad-spectrum ones should be used only when required (Edwards et al, 1986). The strategic use of anthelmintics only at times of high incidence, and based on epidemiological information and disease forecast, can help delay the onset of resistance. Pasture and animal management for parasite control should be integrated as much as possible to reduce the dependence on anthelmintics. The alternation among the three groups of broad-spectrum anthelmintics, benzimidazoles, and probenzimidazoles; imidazothiazoles and tetrahydropyrimidines; and avermectins and milbemycins, at approximately yearly intervals has been recommended (Coles and Roush, 1992) and adopted by advisory agencies. Anthelmintics should also be used at dose rates that cause the highest economically feasible parasite kill in order to restrict genetic variability and render any resistance genes effectively recessive. The administration of mixtures of anthelmintics may be effective if multiple resistance exists (Anderson et al, 1991; Barnes et al, 1995), but success depends on the magnitude of resistance (Waller et al, 1990). The use of a combination of anthelmintics or of anthelmintics at dose rates exceeding the manufacturer's recommendations is not necessarily effective (Waller et al, 1990). When resistance to broad-spectrum anthelmintics develops, it may be necessary to use flukicidal drugs such as closantel against resistant blood-sucking nematodes such as *H. contortus*, which is done in the Wormkill program in Australia (Taylor and Hunt, 1989). Current evidence suggests that reversion does not occur (Hunt, 1997). Strategies for the control of anthelmintic-resistant nematodes in ruminants include reduced use of anthelmintics, use of a full dose, annual alternation of classes of anthelmintics as outlined above, and annual checking of the program by the veterinarian, with emphasis on the use of a fecal egg count reduction test as part of the health management program (Coles, 1988; Hunt, 1997; Craig, 1998). Larval development assays have also been described to evaluate compounds from egg hatching to third-stage larvae whereby the larvae are grown in a medium containing varying concentrations of anthelmintic (Amarante et al, 1997).

The basis for the control of parasitic gastroenteritis in sheep is a combination of the strategic administration of anthelmintics and reduction in the rate of reinfection by appropriate grazing management, such as movement to safe pastures. If safe pastures are not available, it is necessary to give repeated doses of anthelmintics during the most dangerous periods. The guidelines in Box 16-21 are recommended.

Fasting sheep overnight before drenching may increase the efficacy of benzimadole anthelmintics (Ali and Hennessy, 1995) but not ivermectin (Escudero et al, 1997) or levamisole (Charlier et al, 1997). Low-volume doses of a benzimidazole compound administered directly into the rumen increase their bioavailability (Hennessy et al, 1997), but this route has only been commercially exploited in cattle.

Internal parasite control programs differ markedly from place to place depending on the climate, with the major variable being *H. contortus*. In its absence, such as in a winter rainfall area, it is necessary to drench adult dry sheep only twice each year, breeding ewes three times and lambs twice. This is because the hot, dry summer is damaging to larvae, and the larval pickup is small. The same advice applies to countries with cold winter climates.

Adult dry sheep should be drenched at least once during the summer to eliminate the parasite at a time when pasture conditions are lethal to the larvae, and thus to clean the pasture of infection for the dangerous period ahead: the warm, moist autumn. The general recommendation is for two summer drenches: the first as soon as the pasture has dried off and the second in midsummer. A spring drenching can also be included with advantage. This disposes of any existing worm load so that the sheep can make best use of the spring flush of feed.

Breeding ewes get an additional drench either just before or within 3 weeks of lambing. The purpose is to avoid heavy contamination of the environment for the lambs and to enhance the ewe's milk supply.

Rams receive a prebreeding drench along with the other adult sheep in the summer drench program.

Lambs on pasture should be drenched at weaning to avoid their succumbing to the stress of weaning plus the burden of a parasite infestation. In lambs born in autumn into bad situations, or if there is any evidence of worm infestation, another drench may be given in midwinter while the lambs are still on the ewes. Lambs still on ewes should not need drenching when they are not yet grazing much.

The treatment of all purchased sheep (Barnes et al, 1995) is very important to prevent the introduction of resistant nematode strains.

This is a sample program that would be applicable in certain circumstances. It is not possible to make more specific recommendations. It presupposes that a broad-spectrum anthelmintic is used and that there is no problem of anthelmintic resistance in the resident worm population.

Summer Rainfall Areas. In this type of climate, the conditions on the pasture during the summer months are favorable for larval survival and pickup may be heavy. This is especially true for heavy egg layers such as *H. contortus*. One or two summer drenches cannot therefore prevent pasture contamination. For flocks that lamb in the spring, two drenches are given to the ewes at lambing, one before and one after the lambing period. Lambs are drenched at weaning and then monthly for 6 months. This intensity may be reduced if safe pasture is available after each drenching. Conversely, a heavier drenching program still may be necessary on heavily contaminated farms during seasons of hot, humid weather.

Monitoring Results of a Worm Control Program. The biggest problem with any worm control program is monitoring its efficacy. In completely standard climatic conditions, the recommended programs are guaranteed to be effective, but only if there is no anthelminitic resistance and if measures for the drenching program and use of rested pasture have been carried out conscientiously. The fecal egg

BOX 16-21

Guidelines for Administration of Anthelmintics

1. Treat ewes before lambing to kill the immature forms of the nematode, which are in the arrested stage of development.
2. After treatment of ewes before lambing, they and their lambs are placed onto safe pastures. When pasture with minimal larval contamination is available, it is beneficial to treat the ewes as they lamb and transfer them at this time in order to clean fields that have been free of sheep for at least 3 months. This should reduce the possibility of large numbers of parasites developing later in the season.
3. When sheep are housed over the winter, before lambing, and then turned out at lambing, the anthelmintic treatment may be given at the beginning of the housing period to reduce any production losses associated with inhibited larvae and adult parasites.
4. When pasture is set stocked and heavily contaminated, a number of anthelmintic treatments of the ewes are necessary over the lambing period. In Australia, where set stocking is common, anthelmintics may be administered to both old and young sheep up to 14 times annually, but this has led to the widespread development of anthelmintic resistance. This has necessitated new strategy schemes such as the Wormkill and Drenchplan systems, which are aimed at reducing the number of broad-spectrum anthelmintic treatments. In many areas of the northern United States and the United Kingdom, a common practice has been to give repeated treatments during late summer and autumn, when pasture contamination and infectivity are high and sheep are already affected with signs of clinical parasitism. Such treatment is only temporarily effective because of immediate reinfection from pasture. Treatment at three weekly intervals in the spring followed by movement to safe pasture after weaning has proved much more effective. Alternatively, a single or double treat-and-move program could be initiated in July, just before the expected increase in pasture contamination ("midsummer rise") occurs.*
5. Parasitic gastroenteritis in sucking lambs is rarely a problem (except for *Nematodirus battus* infestation on contaminated grazing in the United Kingdom), and delaying treatment until weaning with one or two treatments between weaning and autumn may provide adequate control in some countries. Weaned lambs set stocked on pasture may have to be treated at 3-week intervals on three occasions in May and June, and three times in August and September in the United Kingdom and Europe.† If clean pastures are available, treatment at weaning and movement onto the pasture may be sufficient ("dose and move"). If pregnant ewes are housed during the winter months, the anthelmintic can be given at the beginning of the housing period to reduce any production loss associated with inhibited larvae.
6. Ewes and rams are treated before breeding.

*Herd RP, Parker CF, McClure KE: *J Am Vet Med Assoc* 184:680-687, 1984a.
†McKellar QA, Marriner S, Bogan J: *Vet Rec* 122:558-560, 1988.

count reduction test and total worm count at necropsy described earlier are useful tests for assessing anthelmintic resistance. Fecal egg counts alone can be unreliable, but, because of their ease of performance, it is worthwhile to attempt a cautious interpretation of what the counts mean. The problem is created by older adult sheep that have developed a resistance to parasitic infestation so that there may be heavy infestations with immature larvae, which are not laying any eggs at all. The resistance to heavy helminth burdens may be of varying degree and may differ widely among sheep in the same flock. A simple way of overcoming this problem when interpreting fecal egg counts is to use only susceptible sheep as monitors. Weaners younger than 9 months old and ewes in early lactation are the obvious subjects. These sheep should have been drenched with an efficacious anthelmintic about 1 month previously. If the sheep were then grazed on a particular pasture for the ensuing month, their fecal egg burden should be an accurate indication of the infectivity status of that particular pasture. Individual sheep fecal egg counts are not necessary; bulked specimens containing fecal samples from 10 sheep each and two counts per flock are considered adequate for meaningful interpretation. The exercise might be carried out as the condition of the sheep dictates or at regular intervals (e.g., during veterinary visits plus other occasions).

It is possible, therefore, to assess the status of particular pastures, but the more common problem is to determine the parasitologic burden of a particular group of sheep. If the sheep are a susceptible group, they can be tested, preferably when larval pickup is at a high level (e.g., after autumn rain). If the sheep are likely to be partly immune, the testing is much less reliable. Some of the sheep may be passing significant egg loads, but many of them harbor only immature larvae and are passing few eggs.

Safe Grazing. The concept of a pasture carrying no infective nematode larvae is difficult to translate into reality in many sheep-rearing areas. Nowadays, it is customary to think of safe grazing as pasture on which sheep increase their worm load only slowly after going onto it, having had a prior effective anthelmintic drench. Unfortunately, any significant reduction of helminth larval burdens on pasture can only be relied on in hot summer weather, in which it takes 2 to 6 months of high subtropical temperatures. Paddocks that have been closed to sheep for some time, such as grains or forage crop stubbles and hay paddocks, are best suited as quarantine areas, but they are obviously limited in their availability. It is therefore usually necessary to limit their use to the susceptible groups—young sheep up to 18 months of age and ewes with lambs.

An alternate and moderately effective procedure for reducing pasture contamination is alternate grazing of paddocks by sheep and by cattle. Almost all helminths are species specific, so that cross transmission between sheep and cattle does not occur. The use of alternate grazing with resistant

sheep is much less reliable because these sheep, although they are resistant to the growth of helminths, can produce significant levels of contamination of pasture. Whichever decision is made about how to achieve the least parasitic risk to young sheep, it is often the quality of the feed in a paddock that determines whether it is used for grazing.

Fascioliasis (Liver Fluke)

Fascioliasis causes important economic losses in most regions of the world where cattle and sheep are raised. Heavily infected animals may die, but those less severely affected suffer a substantial reduction of growth and production (McIlroy et al, 1990). Losses caused by reduced production efficiency result in the greatest economic impact of the disease. Fascioliasis can be controlled effectively by strategic attacks on both snails and flukes. One of the most important methods of control used worldwide is the strategic use of modern flukicidal drugs. Because the administration of these drugs is expensive, any advice on the frequency and the most effective timing of their use must depend on the estimated annual risk of the disease forecast in any region (Morris and Meek, 1980).

The use of a computerized information retrieval system of abattoir and meteorological data to formulate a sophisticated mathematical model can accurately forecast the annual prevalence of fascioliasis (McIlroy et al, 1990), which enables the formulation of an effective control strategy.

A cost-benefit analysis of a control scheme, based on the prevention of snail infection by *Fasciola hepatica* by treating ewes grazed on fluke-infested riverine land with four treatments/ewe of triclabendazole, was compared with the costs of leaving the sheep untreated (Clarkson, 1989). On a farm with 1800 ewes, the total loss from failure to treat was estimated to be £8272 annually because of reductions in lamb carcass and fleece weight. In contrast, the cost of treatment would be only £864 annually.

Psoroptic Mange

Since reintroduction in 1973, psoroptic mange was controlled in the United Kingdom by twice-annual compulsory dipping during the spring and autumn, with fewer than 16 cases reported during 1988. Removal of these dipping controls in 1989 has lead to widespread infestation of the national flock (Lewis, 1997) with serious welfare as well as production consequences (Sargison et al, 1995; Bellworthy et al, 1997; Corke, 1997). The single subcutaneous injection of doramectin has proved highly effective in the treatment of psoroptic mange (Purnell, 1997) and forms the basis for disease control in the United Kingdom. Presently, there is no sheep scab eradication program operating in the United Kingdom.

Blowfly Strike

Sheep blowfly strike, cutaneous myiasis, or infection of sheep skin by fly maggots is the largest single cause of death and production loss to the sheep industry in Australia (Sandeman, 1989). An estimated 3 million sheep die each year of flystrike and its complications. Cutaneous myiasis is also reported to be a serious problem in Hungary (Farkas and Hall, 1998), as well as a major welfare concern worldwide (Groves, 1997). As many as 500,000 sheep are struck annually in the U.K. national flock of 30 million sheep (French et al, 1992). In North America and Europe, it is primarily a problem secondary to diarrhea in lambs with parasitic gastroenteritis and occasionally mycotic dermatitis. Blowfly strike is a preventable disease and continues to be a major disease whenever susceptible sheep are pastured in large groups, only because farmers fail to use available control techniques (Anderson, 1990). Merinos seem particularly susceptible to flystrike because of their fleece structure, but other breeds are also attacked. Although the merino fleece is slower to wet after rain than other breeds, once wet it remains so for longer, allowing bacterial growth and skin inflammation to create conditions for fly oviposition and maggot survival (Sandeman, 1989). In addition to wet wool, several skin conditions can predispose sheep to blowfly strike through the attraction of female flies to oviposit. Infected wounds, bacterial dermatitis, footrot, urine or fecal scalding, and sweating, especially around the horns in rams, can create ideal conditions for flystrike. Lambs and hoggets are the most susceptible age group both to infection and the pathogenic effects.

The only satisfactory way of dealing with the problem is to maintain a long-term strategy of reducing the susceptibility of the sheep and to combine this with a standby short-term emergency tactic that can deal with an infestation urgently and effectively. The indirect methods for controlling flystrike include timely shearing, breeding to reduce susceptibility, tail docking, crutching, the use of insecticides, and the control of nematodes and ectoparasites. The direct methods include blowfly bait bins and traps and the treatment of existing flystrikes. The details of flystrike as it occurs in Australia have been presented and reviewed (Anderson, 1990).

Mules Operation

It has been claimed that correct mulesing (or breeding for a plain breech) and tail docking (Yeo, 1981) are the long-term strategies that can effectively eliminate the greater part of the sheep's susceptibility to blowfly strike. This mutilation (mulesing) is performed on Merinos and other wool breeds such as the Columbia, with excessive wrinkling. It is usually not required in the meat breeds and has never been undertaken in European countries or in North America in any breed. The mutilation involves removal of the perianal skin to stop wool growth and, with tail docking, to reduce the possibility of urine or fecal staining on the breech. The mutilation is carried out without analgesia through the use of sharp shears on the skin wrinkles of the breech and tail, which are presented to the operator rump-down with the area exposed and accessible. The folds are removed by cutting with the shears (rather than a scalpel), using a scissors action, and making sure to start with sharp V cuts rather than blunt starts. The widest part of the denuded area should be just above the vulva. The mutilation must be performed in clean surroundings with disinfected instruments, and the lambs left undisturbed for 3 to 4 weeks to give the wounds time to heal. It is almost unbelievable that no careful study of costs and benefits appears to have been carried out for mulesing and prepuce dropping. Many veterinarians have expressed grave concern over mulesing.

Docking of the tail is claimed to be critical in the control of blowfly strike. The tail must be removed between the second and third vertebrae. A too-long tail means fouling and strike susceptibility in those flocks in which parasitic gastroenteritis is not effectively controlled. Too short of a tail means a high prevalence of skin carcinoma of the vulva.

Tail docking and mulesing, if properly performed over a period so that the flock is wrinkle-free on the breech, are claimed to reduce the size of the fly population as well as the chances of infections occurring in the less common sites of the back and the pizzle.

Because of the possible importance of the preputial area as a site of carryover infection in winter, two methods have been devised to reduce the susceptibility of this area. A

chemical ringing method creates a bare area of scar tissue around the prepuce and reduces the chances of wetting. The other technique, prepuce dropping, consists of severing the anterior attachment of the prepuce to the abdominal wall. This has a similar effect of reducing urine staining of wool.

The principal disadvantage of these techniques is that they are painful and unnecessarily mutilating. Although considerations of animal welfare must direct increasing attention to the long-term project of breeding less susceptible sheep with plain breeches, this does not appear to have a high priority with farmers nor veterinarians in Australia.

Timing Shearing Correctly

The less wool a sheep is carrying at the time of high risk, the less the chance of infestation. If the time of major fly infestation can be coincided with a prior shearing, much of the risk to heavy-wooled sheep can be avoided.

Avoiding Fleece Rot

Fleece rot has become prevalent and is conducive to blowfly body strike. Breeding to reduce susceptibility and development of a vaccine against it are strategies of potential prophylactic importance. Body strike is relatively uncommon, and outbreaks last for relatively short periods, but the disease is severe and heavy losses result (Watts and Merritt, 1981).

Control of Gastrointestinal Helminthiasis

Prevention of the diarrhea that accompanies trichostrongylosis in sheep helps to keep the perineum clean and less attractive to blowfly strike; it is the single most important factor in the prevention of cutaneous helminthiasis. Effective control of parasitic gastroenteritis has been outlined elsewhere in this chapter.

Chemical Treatment. Chemical treatment has been the major method of control since the 1950s and the introduction of the organophosphates (Sandeman, 1989). Fly resistance to organophosphates is now common, and protection lasts only 3 to 4 weeks. Newly introduced prophylactic drugs include cyromazine, a larval growth inhibitor (which protects for up to 12 weeks and is well established in the market), and synthetic pyrethroids, including cypermethrin, which inhibit oviposition. Organophosphorus compounds are still used for the treatment of fly strike, but there are serious human health considerations and great care must be exercised when handling these products. Organophosphorus compounds inhibit cholinesterase, thereby interfering with neuromuscular transmission. A major objective is to use a chemical to which the local blowfly larvae are least resistant. The practitioner must watch this carefully. Most areas with a local problem monitor the sensitivity of maggots continuously. Lucilia cuprina is the most prevalent fly in Australia (90% of strikes are by this fly) and the only one to be resistant (Wharton and Norris, 1980). Resistance has developed to all modern insecticides—including aldrin and dieldrin, carbamates, and organophosphates—but cyromazine is still effective (Anderson, 1990).

When the first sheep are struck, the rest must be jetted immediately (or some other effective means of application used). The machinery needs to be adequate to the task. Sheep handling facilities need to be able to handle the numbers quickly and the insecticide needs to be formulated so that it can be administered rapidly using the available equipment.

Other Approaches. The current control procedures described earlier are costly, are labor intensive, create fly resistance, and provoke concern from animal welfare activists and many veterinarians. Some new approaches are being explored. Genetic manipulation to produce and release sterile male flies similar to the program used for the control of the screwworm fly in the United States may show promise. The release of organisms that are pathogenic to the first instar larvae is also a possibility (Sandeman, 1989). Breeding for strains of sheep that are resistant to fleece rot is also being examined. A vaccine against *Pseudomonas aeruginosa*, a major cause of fleece rot, is currently being field tested, and initial results have suggested that the vaccine could control fleece rot initiated with the organism and natural flystrikes. A vaccine against the maggot antigens may also be possible.

Footrot

Footrot is one of the most important contagious diseases affecting the sheep and wool industry. No single completely satisfactory and cheap method of control has yet been found, and specific diagnosis continues to be difficult. However, much is known about the cause and epidemiology of the disease that can be applied toward effective control and eradication of the disease from a flock. In countries where footrot is a problem (e.g., Australia, New Zealand, and the United Kingdom), veterinary involvement has usually been restricted to research, to regulatory activities, and to extension (Egerton, 1989). Effective control of the disease depends on veterinary involvement directly on the farm.

Dichelobacter (Bacteroides; Fusobacterium) nodosus, the causative agent of footrot in sheep, is an obligate organism that cannot exist independently from ruminants' feet, and eradication requires only that all cases of footrot be recognized and removed. Therefore accurate recognition of the disease and differentiation from other diseases of the foot is necessary. Two clinical forms of footrot, virulent and benign, have been recognized for over 40 years (Stewart et al, 1986). The severity of the foot lesion is principally dependent on the particular infecting strain of *D. nodosus* (Winter, 1997), and such strains have been classified as virulent or benign. The organism possesses a spectrum of virulence for sheep, with a consequent disease continuum ranging from complete lack of effect, to mild interdigital skin lesions, to underrunning lesions in a varying proportion of feet, to severe necrotic separation of the horn of the hoof in the majority of feet (Stewart et al, 1986b). Recently, a particular virulent form of footrot has been described in the United Kingdom (Grogono-Thomas, 1997), where sloughing of the entire hoof capsule has been recorded (Winter, 1997).

Virulent or progressive footrot is characterized by extensive separation, which commences at the heel, extends centrifugally to the sole and toe, and frequently extends up the abaxial wall, with the formation of a foul-smelling, necrotic exudate. In benign or nonprogressive footrot (scald), occasional separation of the horn of the heel bulbs and posterior sole region occurs, but there is little accumulation of necrotic material under the separated horn. Benign footrot causes only mild lameness and rapidly regresses after topical treatment or after the onset of dry environmental conditions. Virulent footrot causes severe chronic lameness and tends to persist after the onset of dry conditions, unless intensive treatment is undertaken.

Footrot is a debilitating disease that can cause serious economic losses to the meat and wool industries of many sheep-producing countries. Field observations have suggested that some sheep flocks are less susceptible to footrot than others, and there is some circumstantial evidence for an inherited factor being involved (Bulgin et al, 1988). The progeny of Targhee rams are more resistant to footrot than those from footrot-susceptible rams (Bulgin et al, 1988). The genetic and phenotypic parameters for clinical foot

scald and footrot were investigated in a pedigree flock of New Zealand Romney sheep during outbreaks over a 6-year period (Skerman et al, 1988). Selection of the top 5% of progeny-tested sires for breeding could be expected to reduce the prevalence of footrot by approximately 45% per generation (Skerman et al, 1988). If the mechanism of resistance to footrot in sheep can be determined, a marker for the identification of resistant sheep might be found (Bulgin et al, 1988). The prospect of controlling such an important disease of sheep by genetic selection is attractive.

Footrot in sheep can be controlled at a low level of prevalence or eradicated from the flock. Vaccination alone reduces the prevalence in flocks and protects a high proportion of sheep at risk for a limited period (Egerton, 1986). Control is not an adequate long-term solution, however, and eradication should be the aim, but eradication is an expensive proposition and should not be attempted unless the producer and others involved appreciate all the costs, including labor, that are essential to success (Egerton, 1986). The strategy for eradication of the disease is based on the principles of eradication of infectious diseases, the epidemiology of footrot, and the selection of the most practical methods of eliminating virulent *D. nodosus* infection if neither depopulation of the flock nor the sale of affected animals is an option (Egerton, 1986). The important principles of eradication include diagnosis, reduction of the prevalence, elimination of infection, and surveillance. An accurate clinical diagnosis based on visual and manual examination is necessary. Careful examination of all feet of every sheep in the diseased flock is required, with extensive paring to expose and remove all pockets of infection. Sheep with overgrown and misshapen hooves should be examined carefully. The prevalence must be reduced to a level at which eradication becomes feasible. The elimination of infection from source animals is dependent on effective chemotherapy. After eradication of the disease from a flock, constant surveillance to prevent entry of the infection into the flock or the early detection of new cases and their elimination is necessary to maintain disease-free status.

The important epidemiological characteristics that are relevant to the eradication of footrot in sheep are shown in Box 16-22.

The traditional strategy for handling an outbreak of footrot in sheep was to adopt control measures to contain the disease until dry summer conditions were present, followed by an attempt at eradication. Commercial footrot vaccines containing representatives of the major serogroups of *D. nodosus* are now available as an aid in control and for the initial stages of eradication of footrot in sheep (Stewart et al, 1986a). The vaccines in use require water-in-oil adjuvant systems to achieve acceptable levels of efficacy and duration of immunity. The vaccines have the capability to prevent footrot and to accelerate healing. They can be used to control an outbreak of virulent footrot in previously unaffected sheep, which occurs when seasonal conditions favor transmission. The development of immunity takes about 3 to 4 weeks after vaccination, and it is unlikely that control of a new outbreak could be achieved without also running the animals through a foot bath of 5% formalin. The vaccine is also effective for control after transmission has ceased. Vaccination at this time is primarily for the therapeutic effect and to prime the sheep for a rapid response to future doses of vaccine (Egerton, 1986). The vaccine accelerates healing and reduces the prevalence to a level at which eradication, either by disposal or individual chemotherapy, is feasible. If eradication has not been completed because of unfavorable conditions, and if continued control is the option, revaccination can provide continued protection. If only control of the disease is the objective, annual revaccination can maintain the prevalence at a low level. Vaccines cannot eradicate the infection from the flock.

Chemotherapy with and without foot paring has been a long-standing option for the clinical management of footrot in sheep. Topical treatment with 10% zinc sulfate solution or a 5% formalin foot-bath is an effective method. Zinc sulfate foot bathing is highly effective for the treatment of footrot in sheep (Winter, 1997), except in those animals that have lesions located beneath the hard horn of the toe or beneath the hard horn of the outside wall in the vicinity of the toe. These feet must be pared and retreated for a cure to result. After paring, the sheep stand in a 10% zinc sulfate solution for at least 30 minutes, and then twice more, 1 week apart, with no further paring. Thorough inspection of the feet and foot paring were traditionally deemed necessary for the effective control and eradication of footrot. Examination of all feet and paring before treatment with a foot bath of zinc sulfate or vaccination have revealed that paring is highly effective (Plant and Claxton, 1986).

An economic evaluation of various treatments for footrot in sheep, by decision analysis, revealed that of 32 treatment regimens tested, the use of 10% zinc sulfate applied to the feet of affected sheep was the most cost-effective, regardless of the prevalence of the disease or its impact on productivity (Salman et al, 1988a). Parenteral treatment with antibiotics, especially streptomycin-penicillin combination or 10% oxytetracycline (Winter, 1997), is also effective. In some areas the use of formalin is decreasing because it is believed to not penetrate the hoof wall as much as previously thought; it is perceived by producers to be painful when splashed on the skin of the legs and the udder; producers find it unpleasant to use; it is considered a carcinogen; and zinc sulfate is cheaper, safer, and more effective.

The strategy for the eradication of footrot is shown in Box 16-23.

BOX 16-22

Epidemiological Aspects of Eradication of Footrot

The carrier sheep is the only significant source of the organism and infection is often introduced on to the farm with the puchase of carrier sheep. The organism survives on pastures, mud, and soil for only a limited time. Keeping pastures free of sheep for no less than 2 weeks during peak transmission periods ensures that they are clean (Stewart et al, 1986a). Infected sheep must be identified by careful examination and trimming of all feet, and the infection eliminated by treatment or culling from the flock.

Transmission of infection is at its highest peak during wet seasons. Eradication should only be attempted in dry periods after the pastures have dried and transmission is no longer occurring. In Australia, midsummer to early autumn is often a good time for an eradication program.

Clostridial Diseases

Enterotoxemia, botulism, tetanus, blackleg, black disease, malignant edema, and focal symmetric encephalomalacia can be significant causes of loss in sheep flocks, usually as massive outbreaks. Perhaps because they are easily controlled by vaccination and do not specifically require changes in management, they are generally kept under

BOX 16-23

Strategy for the Eradication of Footrot

1. Eradication should be attempted only during a dry period.
2. The feet of all sheep are examined and affected sheep are segregated. Clean sheep are put through a foot bath of 5% formalin or 10% zinc sulfate and placed in clean fields.
3. Affected sheep are treated by paring of the feet, foot bathing with zinc sulfate or formalin, and treated with an antibiotic parenterally or vaccinated. Foot bathing must be repeated weekly for at least three treatments. Sheep that do not respond must be retreated intensively or culled. Those with grossly misshapen feet should be culled. Foot bathing may have to be continued throughout the summer months so that the infection is eliminated. This strategy should reduce the prevalence of the disease in the flock.
4. Constant surveillance is necessary to ensure that no affected sheep have been classified as unaffected and to determine response to treatment. Surveillance must be maintained until no cases of footrot are found in the treated or untreated sheep. Absolute eradication can be declared when there are no cases in the flock during a subsequent period of weather favorable for transmission.*

*Egerton JR: Control and eradication of ovine footrot. In Stewart DJ, Pearson JE, McKern NM, Emery DL, editors: Footrot in ruminants, Proceedings of a Workshop, 1985, Melbourne, 1986, Australian Wool Corporation.

control. It is usually because vaccination programs are allowed to lapse or because the diseases occur out of season or in normally free areas that outbreaks occur.

Maedi-Visna

Maedi-visna, or ovine progressive pneumonia, is a slow virus disease of sheep characterized by chronic interstitial pneumonia, encephalitis, chronic arthritis, and chronic indurative mastitis, usually observed clinically in sheep 2 years of age and older (Watt et al, 1994; Watt et al, 1995). Both forms of the disease progress slowly and are inevitably fatal. In many cases the disease is subclinical, but infected sheep are carriers of the virus for their entire lives and propagate the infection. The disease can be an important cause of economic loss in sheep flocks because of adult mortality resulting from chronic pneumonia and unthriftiness and the increased incidence of culling ewes before the end of their productive life. Infection can lead to reduced conception rates, lower lamb birth weights, and lower lamb weights at 25 to 50 days of age (Dohoo et al, 1987). The disease is prevalent in sheep populations of many countries, especially southern European countries, where serologic evidence has suggested that up to 90% of flocks may be infected. The virus is transmitted from the infected ewe to her lambs through the ingestion of colostrum and milk. Infection of the mammary gland associated with the disease may account for the lactogenic route of spread and for the chronic mastitis that is common in infected sheep. Infected sheep can be detected with serologic tests such as the agar gel immunodiffusion (AGID) test and the enzyme-linked immunosorbent assay (ELISA) test.

Two practical methods for control of the disease have been used. In one method, colostrum-deprived lambs are reared artificially in isolation. In the other, routine serologic testing and subsequent culling of seropositive reactors and their progeny is carried out until the prevalence of seropositive sheep decreases gradually and a seronegative flock is achieved. Under field-type Canadian farming conditions and good management, the disease can be eliminated by the two control programs (Williams-Fulton and Simard, 1989). The test and cull program is more practical, but the first method of rearing colostrum-deprived lambs in isolation to develop a seronegative flock is more effective.

A summary of the control procedures used in the management of other common disease entities in sheep is presented in Table 16-9.

SHEEP HEALTH ACCREDITATION SCHEMES

National health schemes have been established in the United Kingdom to provide data on the health status of specific flocks of sheep (Linklater, 1989). The accreditation scheme for the control of maedi-visna in sheep has approximately 3500 members, almost exclusively pedigree ram breeders. It is based on a system of blood testing and isolation to identify flocks that are free of infection and, once they are decreed to be free, to maintain them as such. The health status is monitored by periodic blood testing, and there are strict rules regarding movement of animals, presentation of animals at sales, and isolation from animals not within the scheme. The major benefit of the scheme is the certification of animals for sale purposes; exports of live sheep from the United Kingdom have been banned since the recognition of bovine spongiform encephalopathy.

The Scottish Veterinary Investigation Service has developed another health scheme for sheep aimed specifically at the commercial sheep producer (Premium Health Scheme [Synge, 1996]). Its purpose is to establish a register of sheep flocks of a high health status based on freedom from enzootic abortion and on vaccination immunity to the clostridial diseases and pasteurellosis. The flock is monitored for enzootic abortion by submitting all aborted fetuses, along with placentae, for examination by a veterinary diagnostic laboratory for evidence of chlamydial infection, the blood sampling of all aborted and barren ewes, the blood sampling of a statistically derived portion of the flock between 1 and 3 months after lambing, and the blood testing of all purchased female animals if they do not come from an accredited flock. Vaccination against enzootic abortion is not permitted because it affects the results of the serologic tests. For the vaccination program, lambs destined for sale must all receive two doses of a multiple-antigen clostridial vaccine, according to the manufacturers' recommendations, with the second dose being given at least 2 weeks before the sale. All lambs must also receive two doses of *Pasteurella* vaccine before the sale.

The breeding stock presented for sale from these flocks are certified by farmers who testify that they have abided by the rules of the scheme and have vaccinated the animals as instructed, by the veterinarian who testifies that the appropriate number of ewes in the flock have been sampled, and by the veterinary investigation officer who testifies that evidence of enzootic abortion has not been found. The advantages of the scheme are that the risk of spreading enzootic abortion is reduced because all abortions are being monitored, ewe lambs sold for breeding are fully vaccinated for clostridial diseases and pasteurellosis, and each producer receives a certificate of full accreditation for the flock, which is

TABLE 16-9

Summary and Control Procdures Used in Some Disease of Sheep

Disease of Production Procedure	Monitoring Technique(s)	Prophylactic Techniques			
		Management	Vaccination	Medication	Other
Anthrax	Sudden death is the only manifestation	Hygienic disposal of carcasses and other infected material	Excellent results; annual in enzootic areas	—	—
Black disease	Sudden death is the only manifestation	Fluke control as prevention	Excellent results with two vaccinations	—	—
Bluetongue	Clinical evidence of oral and coronet lesions; seroconversions indicate presence of one or more serotypes	Prevent introduction of virus into country	Many vaccines available	—	—
Botulism	Clinical cases of flaccid paralysis in groups of sheep on contaminated food or water	Avoid use of feed or water containing carcasses	Excellent results with type-specific toxoid for enzootic area	—	—
Brucellosis	Serologic testing—complement fixation test, plus physical palpation epididymitis	Run some groups separately: vaccinate and test and slaughter positive reactors	Vaccination effective	—	—
Caseous lymphadenitis	Observe enlarged lymph nodes at shearing	Cull affected sheep; disinfect shearing and marking tools after each sheep	Vaccine available and reduces severity but does not prevent disease	—	—
Coccidiosis	Growth rate, fecal oocytes	Prevent crowding, fecal contamination of feed and water	—	Coccidiostats in feed	—
Contagious ecthyma	Observe lesions on mouth, udder, coronets	Isolate affected sheep; avoid abrasive material in environment	Very effective live virus vaccine	—	Very bad outbreaks in lambs or ewes
Copper poisoning	Clinical cases of hemoglobinuria, icterus, and death	Careful use of copper medication for mistakes in feed/mineral supplementation	—	Penicillamine orally or ammonium molybdate in water	Production disease caused by overstretching lamb's potential
Enterotoxemia	Sudden death of lambs, usually	High feed and good body condition of sheep predispose—reduce them	Effective with two vaccinations	*Clostridium perfringens* type D antitoxin provides temporary protection	—
Fluke infestation	Report from abattoirs, fluke egg counts in feces	Control of snails in pasture water	—	Strategic dosing with effective flukicide	—

Continued

TABLE 16-9—cont'd

Summary and Control Procdures Used in Some Disease of Sheep—cont'd

Disease of Production Procedure	Monitoring Technique(s)	Prophylactic Techniques			
		Management	Vaccination	Medication	Other
Hypocalcemia	Serum calcium and magnesium values may predict, but not a practical exercise; observe cases of recumbency and death	Avoid sudden changes of environment or feed or transport in late pregnant or lactating ewes	—	—	—
Jaagsiekte (pulmonary adenomatosis)	Chronic fatal pneumonia, sporadic cases	Slaughter of clinical cases or slaughter of all sheep in country	—	—	—
Johne's disease	Emaciation, soft feces, wool shedding; serologic tests, necropsy lesions best	Slaughter of positive reactors with eradication as aim	Vaccination possible and effective but not practical unless prevalence high	—	—
Listeriosis	Clinical cases of abortion, septicemia in lambs, circling in adults	Reduce access to ensilage; very cold weather predisposes	Cost-effective vaccine available	Therapy not prophylactic	—
Louping-ill	Clinical cases of incoordination, tremor, paralysis; serologic detection possible	Control of vector ticks by dipping program	Excellent vaccine available	—	—
Lumpy wool	Clinical cases very evident with lumpy discolored wool	Isolate affected animals, avoid grooming and other gear spread of infection	—	Antibacterial dip after shearing	Disease disappears in dry weather
Maedi-visna	Observe chronic pneumonia, indurative mastitis, or encephalitis cases; serologic identification possible	Slaughter of serologically positive sheep; isolate lambs at birth with no colostrum; avoid shed lambing	—	—	Complete slaughter of whole flock advised if prevalence high (?)
Malignant edema	Found dead	Hygiene at lambing, castrating, docking, shearing; disinfect wounds	Highly effective	—	—
Mastitis	Clinical cases and gangrenous mastitis (high % not gangrenous)	Cull affected ewes; change pastures and bedding grounds	None available	Therapy not prophylactic	Dry cow mastitis ointment at time of weaning if prevalence high
Nasal bots	Clinical rhinitis and sneezing	—	—	Strategic organophosphate treatment effective, and ivermectin at any stage of life cycle	—
Nutritional deficiency of: Calcium	Bendability and ease of fracture of bones	Improved general nutrition and provision of specific nutritional deficiency	—		—
Cobalt	Poor weight gain; urine concentration			Reticular "bullet"	

Copper	Poor weight gain; blood copper or ceruloplasmin level			Depot injection	
Iodine	Birth of goitrous lambs			Depot injection iodine	
Selenium	Blood levels of glutathionine peroxidase/whole blood selenium			Reticular "bullet"	
Pasteurellosis	Clinical cases of septicemia and pneumonia	Avoid environmental and feed stress	Vaccines used but efficiency not proven	Feeding tetracyclines common in feedlots or long-acting tetracycline at time of risk	—
Pediculosis	Frequent inspection of fleece of live sheep	Avoid spread by inert objects; maintain good body condition (body score)	—	Strategic dip or spray application	—
Pinkeye	Observe signs of blindness, eyelid spasm, conjunctivitis	Avoid close confinement, long grass, flies	—	Long-acting tetracyclines and/or local treatment of severely affected eyes	—
Pizzle rot	Scabs at preputial orifice; swollen prepuce	Reduced protein in diet; ring shear around prepuce	—	Implant of testosterone in wethers	—
Poisoning pasture plants	Many clinical syndromes represented, especially incoordination	Careful surveillance of pasture area for poisonous plants and elimination	—	—	—
Weeds, trees, arsenic	Clinical cases of abdominal pain, diarrhea, high mortality	Access to dipping fluids must be prevented	—	—	Use insecticides other than arsenicals
Polioencephalomalacia	Clinical cases of blindness, opisthotonos, nystagmus, tonic convulsions	Ensure adequate roughage in diet, and adequate continuous water supply; check pasture for equisetum	—	Dietary supplement with thiamine	—
Pregnancy toxemia	Observe late pregnant ewes with blindness, convulsions, recumbency, ketonuria	Ensure high caloric intake in last third of pregnancy plane of nutrition needs to rise	—	Propylene glycol supplementation of diet effective, but impractical	—
Scrapie	Pruritus, incoordination, paralysis; very long incubation period	Slaughter clinical cases; also slaughter contact sheep or goats in free area, particularly of dam line	—	—	Inheritance a significant factor in cause; selection aids control
Squamous cell carcinoma	Tumors on vulva, ear at high level of prevalence	Leave tail docked at correct length; suggested that susceptibility may be inherited	—	—	Correct length of tail left at docking
Tetanus	Clinical cases of fatal tetanic convulsions	Hygiene at birth, docking, castration, mulesing, shearing	Excellent results; vaccinate ewes annually before lambing	—	—
Urolithiasis	Clinical cases of urolithiasis	Ensure adequate fresh water; balance calcium: phosphorus and adequate vitamin A	—	Add salt or ammonium chloride to diet	—
Weaner ill-thrift	Failure to make adequate weight gains in presence of adequate feed	Gentle handling of young sheep at weaning	—	Copper, cobalt, selenium, vitamin D supplementation	Check for parasite load (fecal egg count)

issued by the Scottish Veterinary Investigation Service on completion of 2 years' testing with no evidence of enzootic abortion in the flock. Market research has indicated that buyers pay a substantial premium for breeding stock that has participated in these schemes (Linklater, 1989), although the recent introduction of a highly efficacious chlamydial vaccine questions whether this premium will be maintained. The establishment of a naive flock must be considered carefully because of the ease of disease transmission in areas with a high sheep density.

Health accreditation schemes exist for ovine brucellosis in all sheep-raising states of Australia and in New Zealand. In addition, there is a scheme for footrot control in New South Wales (Plant, 1989). An accreditation scheme either can be totally voluntary, in which a service is provided to interested producers, or it may be part of an overall campaign in which voluntary accreditation may progress to compulsory eradication as disease frequency decreases. All the brucellosis schemes are similar. The major objectives are to supply brucellosis-free rams for sale to sheep breeders and to control the spread of infection by marking rams and urging owners to sell them for slaughter. A major goal is to eradicate ovine brucellosis from most major stud flocks. The main benefits to the participants are increased flock fertility and higher sale prices. Owners organize testing of the rams through their private veterinary practitioner, and diagnostic laboratories of the Department of Agriculture provide the laboratory service and coordinate the scheme. Initial accreditation of the flock is for 12 months and, after 3 years of accreditation, retesting is undertaken every few years thereafter. Indicators of progress include the number of accredited flocks compared with the total number of registered flocks, the number of registered rams supplied against the number of ram replacements needed, the number of breakdowns in accredited flocks per year, and the percentage of flocks seeking accreditation that had positive rams on initial testing. In New Zealand, the ovine brucellosis eradication scheme has been enlarged to include commercial flocks and stud flocks. The scheme has eliminated the spread of infection from ram breeding flocks to commercial flocks.

The footrot scheme in New South Wales commenced in 1989. The main aim was to improve the productivity and welfare of sheep and goats by the progressive eradication of virulent and intermediate footrot. Strategies for control include detection of infected flocks through surveillance, particularly of high-risk groups, and implementation of treatment and preventive measures for footrot (Plant, 1989).

Health accreditation schemes are a form of disease control with voluntary participation by producers. Planning for such schemes needs to be comprehensive and should include a clear statement of objectives and a comparison of likely benefits and costs. The schemes should be largely self-funding, with the assistance of some public monies. Such health schemes are good examples of the integration of government and private veterinary services for the benefit of the wider community. The strategies for control must take into account the transmission cycle of the agent and the role of reservoirs. The unit of interest in assessing progress is the flock rather than the individual animal and progress indicators should be used to assess the level and rate of progress in achievement of objectives.

CONTROL OF INTERNATIONAL SPREAD OF INFECTIOUS DISEASES OF SHEEP

Many infectious diseases of sheep can be spread from one country to another by the importation of infected sheep. Prevention of the introduction of these diseases requires strict import and export controls by the veterinary authorities of the exporting and importing countries (Watson, 1984). National protection against the importation of animal disease depends on a strong, well-organized, and centrally controlled veterinary service in the exporting country, which should have an efficient system of disease reporting along with good testing systems to certify animals free of disease before they are exported. The importing country depends heavily on certification by the exporting country that the animals being exported are free of the infection, and that the disease has not existed in the flock of origin for certain periods of time before export. The importing country also needs an efficient, centrally controlled veterinary authority that can test imported animals in quarantine and that has procedures for isolating and monitoring animals on the farms of destination (Watson, 1984).

The infectious diseases of sheep that are of concern in international trade include bluetongue, contagious agalactia, *Brucella ovis*, maedi-visna, scrapie, foot-and-mouth disease, sheep-pox, and infection caused by *Brucella melitensis*. Serologic and other diagnostic tests are available for some of these diseases, such as bluetongue and maedi-visna, but for others (e.g., scrapie) there is no diagnostic test; certification is dependent on the flock of origin being certified free of the disease for a certain number of years (Watson, 1984). The international expansion of trade to meet the mounting pressure of agricultural interests for improved breeds depends on an extension of national flock eradication programs and on the establishment of flocks with superior health status for diseases such as maedi-visna and scrapie.

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