Equine nutrition

INRA nutrient requirements, recommended allowances and feed tables

edited by:
William Martin-Rosset

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INRA
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Institutes

AFZ
Association Française de Zootechnie – French Society of Animal Science

CEZ
Centre of d'Enseignement Zootechnique – College for Animal Science Education

CNRS
Centre National de la Recherche Scientifique – National Center for Scientific Research

Enesad
Ecole Nationale d'Enseignement Supérieur Agronomique de Dijon – National School for Agricultural Sciences of Dijon (to date: Institut National Supérieur des Sciences Agronomiques, de l'Alimentation et de l'Environnement – National Institute for Agricultural, Feeding and Environmental Sciences)

ENV Nantes
Ecole Nationale Veterinaire, Agroalimentaire et de l'Alimentation de Nantes-Atlantique – Nantes-Atlantic National College of Veterinary Medicine, Food Science and Engineering

IDELE
Insitut de l'Elevage – French Livestock Institute

Ifce
Institut Français du Cheval et de l'Equitation – French Institute for Horse and Riding

Inra
Institut National de la Recherche Agronomique – National Institute for Agricultural Research

LCH
Laboratoire des Courses Hippiques - Laboratory for horseracing

PNR
Parc Naturel Régional – Regional Natural Parks

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Preface: new feeding standards for equines

The aims of feeding standards

Feeding systems usually provide sets of tables that give, respectively, the nutrient requirements of the animal and the nutritive value of the feeds. Both are expressed according to the same feed evaluation system. These systems must allow:
- an accurate comparison of the nutritive value of feeds;
- the formulation of well-balanced rations to achieve production and utilisation goals;
- the prediction of animal performance when quality and quantity of the ration are known.

An efficient system must have a sound scientific basis and be additive, as simple as possible and capable of further development.

A brief background on research in equine nutrition

Intense research dealing with feed evaluation and feeding working horses was carried out during the late 19th and very early 20th centuries, primarily in Germany and France, where draft and light horses were extensively used in farming and in military cavalry, respectively.

In Europe starch equivalent (SE) or feed unit (FU) for energy, and digestible crude protein (DCP) for protein have been applied successfully to ruminants and then extended to equines as there were not enough data to devise specific horse feeding systems. In the 1920s-1930s research in equine nutrition slowed in Europe while it increased in North America. Total digestible nutrient (TDN) for energy and DCP for protein were proposed by researchers in the USA. Since the 1970s research has again gained prominence in Europe and North America to meet two new challenges:
- to cope with new demand from the racing sector, and prominently from a merging sport and hacking sector rapidly developing in most industrialised countries at the expense of the draft horse and military cavalry population;
- to devise specific feeding systems for equines.

As a result research has increasingly extended knowledge on ingestion, digestion and metabolism of equines as recorded in reports of international meetings initiated in 1968 in the USA and in 1979 in Europe. At present, meetings are organised annually or biannually in Europe by the Horse commission of EAAP (formerly European Association for Animal Production and now so called European Federation of Animal Science) or in USA by the Equine Science Society of ASAS (American Society of Animal Science); two sister organisations. Using primary scientific material published in the proceedings of those meetings, the National Research Council (NRC) of the USA derived a new conceptual framework for evaluating the nutrient requirements of horses based on digestible energy and digestible crude protein (NRC, 1978 – 1st edition). In 1984 the National Institute for Agricultural Research (INRA) in France established new nutritional systems based on net energy, total available amino acids and feed intake. Starting in 2010, new nutritional systems based on metabolisable energy and amino acids absorbed in the small intestine are emerging in Germany.

Research on equine nutrition in France

In the very early 1970s, the National Institute of Agricultural Research (so called INRA: Institut National de la Recherche Agronomique) in France initiated a long term research program strongly supported by the French state. This program was achieved mainly by a research unit entirely dedicated to equines and located in Clermont-Ferrand/Theix with strong support from the National Studs (so called Haras Nationaux and then IFCE – Institut Français du Cheval et de l'Equitation), and contributions of the National Veterinary Schools of Alfort-Paris (ENVA), Lyon (AgroSup Veterinary Campus of Lyon), Nantes (ONIRIS Veterinary campus), and the National Agricultural School of Dijon (ENESAD).

Intensive research was conducted on digestion using digestibility trials and fistulated horses and on metabolism using indirect calorimetry facilities to devise new feed evaluation systems (Chapters 1 and 12) based on net energy and total available amino acids for horse and synthesised by microbial ecosystem. A draft of intake evaluation was attempted considering characteristics of forages (ingestibility) and of animals (intake capacity) because equine livestock feeding in Europe relies heavily on forage based diets derived from natural grassland, rangelands, harvested forages and crop residues (Chapters 1, 9, 10, 11, 12 and 16).

Animal requirements for maintenance, pregnancy, lactation and exercise were determined at INRA using the most modern methods and equipment and 170 horses to design models (Chapters 3 to 7). The requirements (to date, the models) were validated simultaneously using many feeding trials plus a broad range of feedstuffs and diets where nutrient intake and performance results were combined. Studies were conducted on several breeds of horses (French sport breeds – French draft breeds) involving a large number of animals managed in stall/box or pens. Requirements have been established specifically in saddle and draft breeds. Regretfully only race horses were not included in these studies but field observations were included. These long-term studies were conducted at the Experimental Station of IFCE under practical management conditions with 300 horses of either sport or draft breeds; at the National Riding School of Saumur (ENE – Ecole Nationale d'Equitation) with 80 horses (French sport breeds) and the Equestrian centre of the Technological College for Animal Science Education at Rambouillet (CEZ – Centre d'Enseignement Zootechnique) with 24 horses (French sport breeds) under normal use conditions. A very complex plan of studies was necessary to produce the desired results. Planning for adequate support over a sufficient time period to permit the integration of the assessment of nutritional value of feeds with methods of production and processing was necessary (Chapters 10 and 11).

Integration of animal requirements with normal cycles of horse production and use was also required (Chapters 3 to 8). Studies were continued over several years to account for environmental variation in feeding values (forages) and animal performance. The establishment of recommended nutrient allowances for various categories of horses (broodmares, stallions, and growing horses, horses at work, light (riding and racing) horse, and heavy (or draft) horses was possible through this work.

Extrapolation of horse requirements to ponies and donkeys is certainly erroneous. Therefore, requirements and recommended allowances were established specifically for ponies (Chapter 8). The significant contributions of ENESAD and CIRAD (Centre International de Recherche pour l'Agriculture et le Dévelopement in French, and International Agricultural Research center for

Development in hot zones, in English) in developing initial scientific information on the feed requirements of donkeys are also provided (Chapter 8).

Account has been taken, in recent years and to the extent possible, of the various uses of light horses: racing, competitive sport (Olympic disciplines), and pleasure. Much of this information has come from on-site observation and surveys. These have been conducted in France by workers at the National Veterinary Schools of Alfort and Nantes and from INRA in race horse training centres. Data from reports in the scientific and technical literature, included proceedings of ICEEP conferences (International Conference on Equine Exercise Physiology) and published feeding-training programs have been included (Chapter 6). In addition, information generated at meetings organised by the feed industry, such as EEHNC (European Equine Health and Nutrition Congress) or ENUTRACO (Equine Nutrition and Training Conferences) in Europe or KER Equine Nutrition Conferences for Feed Manufacturers in United States, was also considered.

Recommended daily nutrient allowances as established correspond to feeding strategies for each class of animals and major practical situations encountered in the field (Chapters 3 to 8). The daily allowances are average recommendations. They are based on experimental data obtained using a large number of horses managed in experimental facilities under practical conditions to cope as much as possible with individual variation and effect of environment. The range of dry matter intake proposed in the tables is expected to allow equines to meet their nutritional requirements and provide for adequate welfare.

The proposed nutrient recommendations also take into account equine welfare conditions: health and behaviour. Early studies on interactions of nutrition and osteoarticular health, conducted in the 2000s, through the cooperation of researchers of the veterinary schools of Alfort and Lyon, have helped establish the first risk thresholds in preventing certain diseases, such as osteochondrosis in young horses (Chapter 5). Behavioural management techniques for stall-housed horses during this production period have been proposed from behavioural studies conducted at INRA, CNRS (National Centre of Scientific Research) and IFCE as well as in other countries (Chapter 15).

Recommended nutrient allowances optimise the efficiency of utilisation of nutrients and diets by horses and, consequently, contribute to a reduction in waste products. INRA has evaluated this efficiency in order to rank the horse among other farm animals with respect to environmental impact (Chapter 14). Work conducted in recent years jointly by INRA, CNRS and IFCE was used to determine the capacity of the horse to utilise pasture resources and to influence vegetation cover in order to establish its role in preserving biodiversity (Chapters 10 and 14). Work is ongoing to further evaluate the contribution of grazed forage in meeting nutritional requirements of different types of livestock within the context of the systems previously studied.

The recommendations are also based on an extended review of the international literature published between the late 19th century and the early 21st centuries, whatever the origin. This includes the revised edition of NRC in 2007 and new nutritional systems emerging since 2010 in Germany. The principal publications used to support these recommendations are listed at the end of this book (References). They are not all routinely cited across chapters since INRA feeding standards use a systematic approach and are primarily based on two approaches: (1) using a factorial determination of the requirements; and (2) a global evaluation of feed allowances carried out at INRA over all types of horses to be fully consistent and operational (Chapter 1).

Formulating rations (Chapter 2) is currently an easy process. It uses appropriate feeds (Chapter 9), namely properly harvested and preserved forages (Chapter 11) whose nutritive value is displayed in tables (Chapter 16) or can be predicted from laboratory analysis (Chapter 12) and an initial 'by hand' step in the formulation process (Chapter 13) followed by appropriate software.

New INRA edition of Nutrient requirements

INRA, in 1984, published the scientific basis of the new nutritional systems and the first nutrient recommendations in the book entitled 'Le cheval' (INRA, 1984). By 1990 the recommendations had undergone further development and their application specified a particular method and software for ration calculation (chevalRation). A handbook entitled 'Alimentation des chevaux' was published. The book published in 2012 (French edition) and now in 2015 (English edition) describes the scientific bases of the updated INRA nutritional systems, animal nutritional requirements, and the ensuing recommended nutrient allowances within the context of current feeding strategies. It is complemented by several tools dedicated to end-users: 'A practical guide for feeding horses' (only French book edition; translation of this guide is envisaged) coupled with a pedagogic software 'equINRAtion' to learn ration formulation, another practical guide to 'Body condition scoring in horse' (INRA/HN/IE, 1997; an English edition is planned) and finally a pedagogic software 'Rami foraging for Equine' for horse grazing and farming management (edited by IDELE (2014) with contributions of INRA and IFCE; also here an English edition is planned). Together these publications are the result of lengthy and intensive collaborations among the research organisations mentioned above. These nutrient recommendations have been tested successfully in the field since the early 1990s with the strong support of extension organisations IFCE and IDELE dedicated to equine and riding and livestock farming systems, respectively.

These modern systems and ensuing feeding standards can evolve in the future as they are designed according to a step-wise approach robust enough using models and equations where new knowledge may be easily introduced.

This book is the official publication of INRA Nutrient Requirements and Recommended Allowances for Equines.

William Martin-Rosset
Chair of the Committee on Feeding standards

Abbreviations, acronyms and units

Abbreviations and acronyms

AA	Amino acids
ADF	Acid detergent fibre
ADL	Acid detergent lignin
ADG	Average daily gain
AAFCO	Association of American Feed Control Officials
ADP	Adenosine diphosphate
AFNOR	Association Française de Normalisation
AFZ	Association Française de Zootechnie
AIA	Acid insoluble ash
AOAC	Association of Official Analytical Chemists
ATP	Adenosine triphosphate
BCAA	Branched chain amino acids
BCS	Body condition score
BW	Bodyweight
Ca	Calcium
Cal	Calorie
CCME	Canadian Council of Ministers of the Environment
CIRAD	Centre International de Recherche Agronomique pour le Développement (en zones chaudes)
CF	Crude fibre
CK	Creatine kinase
Co	Cobalt
CP	Crude protein
Cu	Copper
CTVM	Center for Tropical Veterinary Medicine
CV	Coefficient of variation
d	Digestibility
d_a	Apparent digestibility
DCAD	Dietary cation-anion difference
DCP	Digestible crude protein
DE	Digestible energy
DHA	Docosahexaenoic acid
DM	Dry matter
DMI	Dry matter intake
DM/100 kg BW	Dry matter intake per100 kg bodyweight
DOM	Digestible organic matter
DP	Total protein content
d_t	True digestibility
EAA	Essential amino acids
EAAP	European Association for Animal Production

EC	Energy content
EC	European Community
EE	Ether extract
EEHNC	European Equine Health and Nutrition Congress
EH	Extra heat
ENUTRACO	Equine NUtrition and TRAining COnference
ESS	Equine Science Society
EU	European Union
EWEN	European Workshop on Equine Nutrition
FAD	Flavin adenine dinucleotide
FAO	Food and Agriculture Organization
FDA	Food and Drug Administration
Fe	Iron
FE	Energy (lost) in faeces
FFA	Free fatty acids
FOS	Fructooligosaccharides
FSH	Follicle Stimulating Hormone
g	Gram
GAG	Glucosaminoglycan
GE	Gross energy
GH	Growth hormone
GEH	Gesellschaft fur Ernahrunggsohysiologie
GnRH	Gonadotrophin releasing hormone
HCT	High critical temperature
HF	High feeding level
HN	Haras Nationaux (National Studs)
I	Iodine
IE (or IDELE)	Institut de l'Elevage (Livestock farming Institute)
IFCE	Institut Français du Cheval et de l'Equitation (French Institute for Horse and Riding)
IFHA	International Federation of Horseracing Authorities
Ig	Immunoglobulin G
IGF-1	Insulin-like growth factor 1
INRA	Institut National de la Recherche Agronomique
IU	International unit
Kcal	Kilocalorie
KER	Kentucky Equine Research
Kf	Efficiency of metabolisable energy in net energy for fattening
Kg	Kilogram
Kg fed	Kilogram feed as fed
Kgf	Kiloforce
Kgm	Kilogram meter
Kl	Efficiency of metabolisable energy in net energy for lactation
Km	Efficiency of metabolisable energy in net energy for maintenance
Kpf	Efficiency of metabolisable energy in net energy for growth
Kw	Efficiency of metabolisable energy in net energy for work

LC	Lignocellulose
LCT	Low critical temperature
LF	Low feeding level
LH	Luteinizing hormone
LVW	Live weight
MAD	Digestible protein
MADC	Matières Azotées Digestibles Cheval (Horse digestible crude protein)
Mcal	Megacalorie
ME	Metabolisable energy
Mg	Magnesium
mg	Milligram
Mn	Manganese
MNBT	Mobile nylon bag technique
MRT	Mean retention time
MSM	Methylsulfonylmethane
MUFA	Monounsaturated fatty acid
MVFS	Minerals and vitamins feed supplement
Na	Sodium
NAD	Nicotinamide adenine dinucleotide
NADP	Nicotinamide adenine dinucleotide phosphate
NDF	Neutral detergent fibre
NDICP	Neutral detergent insoluble crude protein content
NDSCP	Neutral detergent soluble crude protein content
NE	Net energy
NE_m	Net energy for maintenance
NEFA	Non esterified fatty acids
NFE	Nitrogen free extract
NIR	Near infrared reflectance
NIRS	Near infrared reflectance spectroscopy
NPN	Nonprotein nitrogen
NRC	National Research Council
OC	Osteochondrosis
OM	Organic matter
OMd	Organic matter digestibility
OPG	Parasite eggs count per gram of faeces
P	Phosphorus
PDI	Protein truly digested in the small and large intestine
PDIa	Dietary protein truly digestible in the small intestine
PDIm	Dietary protein used for microbial protein synthesis in the large intestine
Ppm	Parts per millions (equivalent to milligrams per kg) protein
PTH	Parathyroid hormone
PUFA	Polyunsaturated fatty acid
R	Total ration
RH	Relative humidity
RQ	Respiratory quotient
ROS	Reactive oxygen species

SAS	Statistical Analysis System
sidCP	Small intestinal digestible crude protein
STA	Starch
TDAT	Total dissectible adipose tissue
TDN	Total digestible nutrients
TFC	Total faeces collection
TNZ	Thermal neutral zone
TP	Thoracic perimeter
UE	Urinary energy
UFC	Unité Fourragère Cheval (horse feed unit)
V	Velocity
VFA	Volatile fatty acids
C_2	Acetic acid
C_3	Propionic acid
C_4	Butyric acid
VO_2	Oxygen consumption
$VO_{2\ max}$	Maximum volume of oxygen consumption
WH	Wither height
WSC	Water soluble carbohydrates
Zn	Zinc
ZNT	Thermo neutral zone

Units

µg	microgram	1 µg = 0.001 mg	
mg	milligram	1 mg = 1000 µg	1 mg = 0.001 g
g	gram	1 g = 1000 mg	1 g = 0.001 kg
kg	kilogram	1 kg = 1000 g	
cal	calorie	1 cal = 4,184 J	
kcal	kilocalorie	1 kcal = 1000 cal	
Mcal	megacalorie	1 Mcal = 1000 kcal	
J	joule	1 J = 0.239 cal	
Kj	kilojoule		
Mj	megajoule		

Chapter 1. Nutritional principles for horses

William Martin-Rosset and Lucile Martin

The recommended nutrients allowances from INRA are based on repeated and parallel scientific studies. Studies of the physiology and metabolism of the horse and of the biology and principal functions of maintenance and production (gestation, lactation, growth and work) were conducted using the most modern methods and instruments (calorimetry, markers, fistulated equine, etc.). Such studies permitted evaluation of the nutritional needs and digestive and metabolic use of nutrients destined to meet their requirements. At the same time, experimental feeding trials were conducted under production and working conditions, which approximated practical situations. Such trials served to validate the physiological and metabolic phenomena observed previously as well as establishing recommended nutrient intakes for different types of horses and functions taking into account normal variability factors. Such a combined approach, original and simultaneously conducted by the same team of researchers, has enabled the establishment and application of modern, applied feeding principles. Knowledge from worldwide scientific sources is integrated in this approach.

1.1 Energy and protein expenditures and requirements – intake capacity and recommended allowances

1.1.1 Definitions and methods

During production periods, horses are producing most of the time. Mares may be growing then gestating and lactating. Males are growing continuously, or discontinuously, from birth until work commences a 2 to 4 years of age. During its working life the adult horse is intensively active in training, racing, or competitive activities, or more moderately as seen in leisure riding.

1.1.1.1 Definitions

Requirements and feed allowances are clearly outlined in the INRA publication. Requirements correspond to physiological expenditures and nutrients measured experimentally in horses in different physiological situations: at rest or in production. The allowances correspond to the quantity of nutrients provided by the appropriate ration to satisfy the horse's needs. These allowances take into account the nutritional value of the feeds determined according to the INRA system and the intake capacity of the horse, in other words the quantity of nutrients consumed. The recommended feed allowances correspond to the nutrients provided by the ration adjusted to obtain the production or use objectives for the horses. These may be less then, equal to, or more than the requirements determined according to technical or economic objectives at a particular moment in the cycle of production or use.

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1.1.1.2 Evaluation methods

Requirements are classically measured using a factorial method. For maintenance requirements are assessed on a limited number of animals (normally 6 per group) by measurement of expenditures over a relatively short period. Energy is determined by calorimetry, protein in balance trials, and minerals by examples, then by using the efficiency of nutrient use for energy and protein or digestibility coefficients for minerals and vitamins. For example, for lactation the requirements are measured from the quantity of milk produced, the amount of nutrients secreted in the milk, and the efficiency of utilisation or from the digestibility of nutrients secreted in the milk.

Allowances are assessed using the global method termed feeding trials conducted with a large number of animals (>10 per group) over a lengthy period (several months, corresponding to a cycle of production or use). In this way account is taken of individual variability, breeds, and effects of environmental factors, where the horses are located in good health and proper management. Ingested nutrient quantities are then related to actual animal performance. This assessment is specific to the particular biological function: lactation, growth, etc.; for each biological function this relationship was studied for a wide range of performances: different levels of milk production, growth and work for horses receiving different types of feeding regimes.

Models were then developed for these relationships in order to calculate nutrient requirements and allowances for each function for the range of situations encountered that corresponded to the principal practical conditions.

1.1.2 Maintenance costs

1.1.2.1 Energy

Maintenance requirements correspond to the quantity of energy required to meet the expenditures corresponding to life and activity of a horse that is not producing or working, and maintains a constant bodyweight with no change in body composition. This requirement is to the horse's metabolic weight ($BW^{0.75}$).

Basal metabolism corresponds to the energy expenditure of an animal in a fasting, resting state and in a thermal neutral environment. It comprises two parts of comparable importance, one part consisting of the maintenance of vital organs (nervous system, heart, lungs, liver, kidneys,) and a second part involving the maintenance of the integrity of cells and tissues, the renewing of proteins, lipids, and transport of ions.

To the basal metabolism, the expenditures associated with ingestion and digestion of food, the excretion of toxic waste, thermoregulation and spontaneous physical activity are added. It should be noted in this connection that in horses, unlike humans and ruminants, standing does not increase energy expenditure compared to the supine position thanks to the very efficient suspensor ligament system. The horse sleeps standing as comfortably as lying. Expenditure was measured by indirect calorimetry and feeding trials in which the quantity of energy necessary to maintain the horse at a constant weight over a long period of time was determined.

In geldings the requirement was established as 84 kcal net energy (NE)/kg $LW^{0.75}$ or 0.0373 UFC/kg $LW^{0.75}$ from data from bibliography sources and INRA studies. This requirement is higher in stallions, sport horses, Thoroughbreds and Trotters (Table 1.1) and lower by 16% in ponies. Individual variation is high, on average, 8%, which is probably due to differences in muscle tone, voluntary activity related to the temperament of the horse. It is also higher in juveniles when compared with older horses: +11%.

Energy expenditure is affected by changes in climate more in hot conditions than in cold, although the horse is capable of adapting. The horse is affected by ambient temperature, conduction, convection, radiation and evaporation, mechanisms that have the effect of increasing or decreasing the amount of heat that must be removed or retained to maintain a constant body temperature of 38 °C. A thermal neutral zone (TNZ) was determined for the horse according to climatic zones. For temperate zones the TNZ is from 5 °C to 25 °C while in cold climates the TNZ is from -15 to +10 °C in the horse acclimated to both zones. The duration of acclimatisation to hot or cold temperatures is on average 3 weeks for the adult horse at rest. It is only 2 weeks for the adult working horse. In cold conditions, the acclimatisation of the horse to the TNZ is efficient because the horse produces a lot of extra heat during the digestion of food, from 20 to 40% of ingested energy. This increases as the proportion of hay in the diet increases. Energy expenditure increases rapidly outside of the TNZ. This increase is 2.5% per degree Celsius below an established TNZ in an environment of -9 to -15 °C. This can increase maintenance costs by 10 to 30%. Expenditures may also be increased 8 to 10% in the summer (+19 °C) in unclipped, adult horses housed indoors in temperate zones compared to measurements taken in winter (+7 °C). In contrast expenditures are slightly reduced in clipped horses.

1.1.2.2 Protein

A 500 kg adult horse has a maintenance requirement of 15 g of protein/kg $BW^{0.75}$, which results in 1,600 g of synthesised protein. The horse, like other herbivores, synthesises 3 to 5 times more protein than would be supplied by ingested amino acids. Most of the amino acids in this process come from degradation of protein in body tissues, as is the case in other animal species.

In this physiological situation, the body of the animal loses nitrogen in the urine and faeces, even if the ration is perfectly balanced with respect to the quantity and composition of proteins and other constituents, such as energy and minerals. These endogenous losses are caused by digestive and

Table 1.1. Variation of maintenance expenditure with sex, breed, activity and exercise.

	Sex		Breeds			
	Male	Female	Draft	Sport	Thoroughbred Trotter	Pony
At rest	+10	0	0	+5	+10	-10 to -15 / sport
Exercising	-	-	+5 to +10	+10 to +25	+30 to +40	+5 to +10
Stallion						
non-breeding			+5	+15	+20	+5 to +10
breeding			+10	+20	+25	+10 to +15

metabolic functions of the organism. Losses of endogenous urinary nitrogen are represented by the products (urea, ammonia) of the catabolism of some of the amino acids, resulting from excess intake and post prandial absorption and turnover of body proteins. Endogenous faecal protein loss results from the fact that proteins of digestive secretions (enzymes, urea and mucus) and the sloughed epithelial cells of are not entirely reabsorbed. A portion is excreted directly, while some is in the form of microbial protein. In any given animal, losses increase with the quantity of dry matter ingested and with the cell wall (crude fibre) content of the ration. These endogenous losses are low in animals consuming a low protein diet but one that is correctly formulated for other nutrients.

Maintenance costs have been established from a body of data (see reference lists) where two types of balance trials were reported. In one the sum of the nitrogen losses was balanced by the quantity of nitrogen intake. The other consisted of feeding trials where protein intake (with energy) resulted in the horses maintaining a constant bodyweight. At maintenance urinary losses are estimated at 128-165 mg of nitrogen/kg $BW^{0.75}$) while faecal losses were 3 g of nitrogen/kg DM. Skin and sweat losses were respectively, 35 mg of nitrogen/kg $BW^{0.75}$ and 1 g of nitrogen/l.

Maintenance protein costs have been calculated at 2.8 g MADC/kg $BW^{0.75}$, which corresponds to a diet containing an average of 5% MADC. This level is most often surpassed, which in certain circumstances may be an advantage, as it may promote growth of the microbial population in the large intestine and better fibre digestion. Maintenance protein costs contribute much less to animal behaviour than does energy, however the two are related. This is why protein intake is expressed in relation to energy intake to take variation into account. The relationship was determined through Kellner's work at 60-70 g MADC/UFC.

Lysine is the only essential amino acid for which the requirement is known: 0.054 g/kg BW. For a 500 kg horse this is $0.054 \times 500 = 27$ g, while the protein requirement is 296 g MADC/day. The lysine requirement is, therefore, $(27/296) \times 100 = 9.1\%$ of the required protein. The maintenance lysine requirement remains, regardless of the weight of the horse, at 9.1% (or $9.1/100 = 0.091$) of the protein requirement and can be calculated: Lys (g/d) = requirement in g of MADC × 0.091.

1.1.3 Production expenses

Production expenses must be added maintenance expenses for mares, young growing horses and horses at work. The relationship of total expenses (maintenance + production) to maintenance expressed as UFC, indicate the level of production by the animal. It is equal to 1 while the animal is at maintenance and increases as the quantity of product increases (milk, weight and work; Table 1.2).

1.1.3.1 Gestation

Mares are normally bred during the first month after foaling. The embryo implants into the uterine wall 150 days after fertilisation. It develops (in terms of weight) slowly up to the 6^{th} month; then very rapidly until term. The weight gain of the foetus represents, respectively, 10 and 90% of the total weight gain during the two periods mentioned above. The foal's development is accompanied by the development of the pregnancy tissues: placenta, foetal fluids and membranes, uterus and udder, which represent 70 to 45% of foetal weight before and after 6 months of gestation.

Table 1.2. Level of production of principal types of horses: relationship between total energy expenditure (UFC) and energy expenditure at maintenance (UFC).

Level	Mares	Young horses Growing – Training		Adult Work			
1.0	Maintenance			Total rest			
	Gestation						
1.15	7th month	12 months					
					Pleasure		
1.3	11th month	12 months					
			Racing				
1.4		24 months	18 months				
1.5	Lactation	36 months		Sports		Sports	
1.6	6th month			36 months			
1.7			18 months				
1.8							
1.9	4th month						Racing
				42 months			
2.0							
2.1	1st month						
			24 months				
2.2	2nd month						
2.3							

Oxygen consumption by the placenta and uterus is elevated from mid-gestation until parturition. Energy requirements of the foetus are met by glucose (85%) and lactate (15%) up to the 8-9th month, after which lipids are mobilised during the last months of gestation especially if the mare is under nourished.

The mare's gestation costs are related to metabolism and growth weight of the products of conception: foetus, membranes and foetal liquids, uterine wall, and the udder, which develops during the last several weeks. Costs are low during the first 6 months of gestation. Then they increase very quickly as the conceptus is rich in proteins fats and minerals. These costs are quantitatively less, however, than the maintenance costs of the mare (Table 1.2). During the 11th month of gestation they are 1.3 and 1.8 times greater than maintenance requirements for energy and protein respectively, and 1.1 to 2.2 for minerals. The development of the foetus and its vitality at birth is heavily dependent on nutritional balance and, notably, any deficiency in minerals, trace elements and vitamins.

1.1.3.2 Lactation

After each pregnancy, the mammary gland, e.g. udder, enters a cycle of growth and tissue differentiation, which develops in three stages: growth during gestation, secretion while lactating and involution at weaning. These changes are under hormonal control: progesterone and oestrogens during gestation, prolactin and oxytocin at the initiation and throughout lactation. Involution is essentially an autolytic process promoted by lysozymes and phagocytic cells that result in the replacement of parenchyma by connective and adipose tissues.

The udder is functional in most cases in the days that precede parturition, as sometimes the colostrum collects on the end of the teats (in layman's terms the mare is said to be 'candling'). Nutrients necessary for milk synthesis are removed from the blood by udder tissues: glucose for lactose, acetate, butyrate and long chain fatty acids for fat constituents and amino acids for proteins. The udder also absorbs water and mineral salts as well as immunoglobulins during the colostral phase. Milk composition varies by month throughout lactation, because of diet, breed and the individual.

Lactation costs are dependent on the quantity of milk produced and its chemical composition. The costs are very high: 2.1 and 2.3 times the maintenance costs for energy (Table 1.2) and nitrogen during the first month of lacatation, because the mare's milk yield is 3.2 kg/100 kg BW. The expenditures are maximal at 2nd month of lacatation, after which they will decrease. The energy expenditures are met by glucose, because mare's milk is rich in lactose and also partially by body lipids (fat reserves), even when the milk is low in fat because feeding programs are inadequate. Protein requirements are met by amino acids in the diet. Mineral requirements are also high at 1.3 to 1.4 times maintenance requirements.

1.1.3.3 Growth

Horses continue to grow to 4 to 5 years of age as this is a species with rapid growth from a very young age after a foetal period of 11 months. Puberty in horses is reached at 15-18 months. In this period the form of the horse changes: during the first year the outline fits into an upright rectangle, in the second year the outline is a square, following which the form is of a horizontal rectangle (Chapter 5). Tissues, organs and anatomical regions grow at their respective speeds. The skeleton develops very early, followed by the muscles, while adipose tissues are delayed in development, but once started they develop very quickly (Figure 1.1). Body composition of the young horse evolves with age; the same as the composition of the daily gain in bodyweight. During this period protein content remains relatively constant, while that of lipids and water increase and decrease in correlation. Mineral content increases.

Nutritional requirements are estimated from the nutrient content of the daily growth (energy, protein, minerals) and daily weight gain. These requirements are more limited compared to maintenance costs as they only represent 1.2 to 1.5 times those for energy (Table 1.2) for the young horse at 1 and 3 years, respectively; 1.2 to 1.9 for protein and from 0.6 to 1.7 for minerals, respectively.

1.1.3.4 Work

The horse at rest has a high spontaneous physical activity in addition to maintenance costs. The horse mainly uses acetate and long chain fatty acids from body sources to meet energy needs. A half hour walk does not change the relative contribution of energy nutrients. Energy expenditure by the horse in a period of activity is, therefore, in a strict sense, greater than the cost of maintenance and is stated to be 1.3 to 2.2 times maintenance for energy, 1.4 to 2.2 times for protein and from 1.1 to 4.0 times for minerals depending upon breed, sex and type of use.

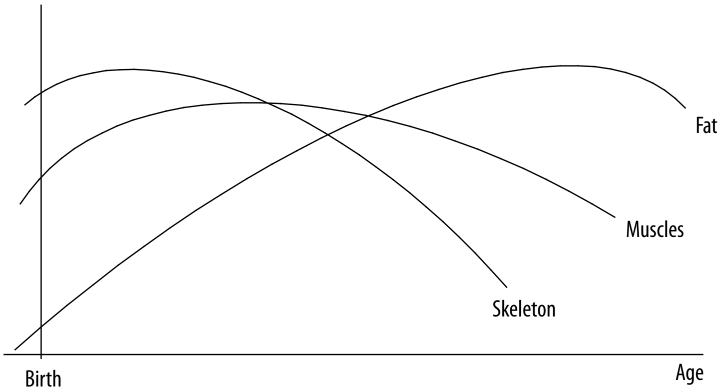

Figure 1.1. Tissue development with age.

The movement of the horse at work produces an increase in energy expenditure compared to rest, which results from the work of skeletal muscles. In addition, there is also the increased work of the cardio-respiratory systems and other organs plus the increase in tone of other muscles.

Exercise of moderate intensity (trot at 300 m/min or gallop at 350 m/min) is performed under aerobic metabolism. The horse meets its need through increasing the oxidative catabolism of glucose as well as long chain fatty acids (Figure 1.2). These energy sources are completely oxidised since aerobic metabolism is predominant. Energy expenditure depends on the duration of work. Under practical conditions work lasts only a very short time, e.g. during an hour of work energy expenditure can be 10 to 20 times maintenance costs (Chapter 6, Table 6.8), but over the length of a day expenditures are 1.7 to 1.9 times maintenance, since the horse only works 1 to 2 hours per day on average, except for endurance competitions. In this latter case a significant part of the expense is covered from body reserves (primarily fat).

At high speeds muscles use preferentially glucose from muscle glycogen (Figure 1.2). Anaerobic metabolism of creatine phosphate and glucose is added to aerobic metabolism, which, although maximised, is not able to meet the increase in energy expenditures required by speed. Anaerobic glucose metabolism results in lactate production, which accumulates in muscles and blood and results on metabolic acidosis and the development of fatigue. The instantaneous energy expenditure of an hour of intense to very intense exercise is 35 to 60 times the instantaneous expenditure at maintenance. The horse covers these expenditures by mobilising body reserves. The energy expended throughout the day is multiplied by 2.0-2.5 times maintenance energy expenditure over a number of days more or less significant depending on the duration of the activity. Protein expenditures are much more limited, less than energy expenditures but are related to these.

1.1.4 Intake capacity

Horses, like other animals consume food to meet their energy needs. Their intake capacity then increases with their energy expenditure. This is the reason that intake capacity is expressed in weight of dry matter per kilo of metabolic bodyweight: g DM/kg $BW^{0.75}$. But the intake capacity also varies

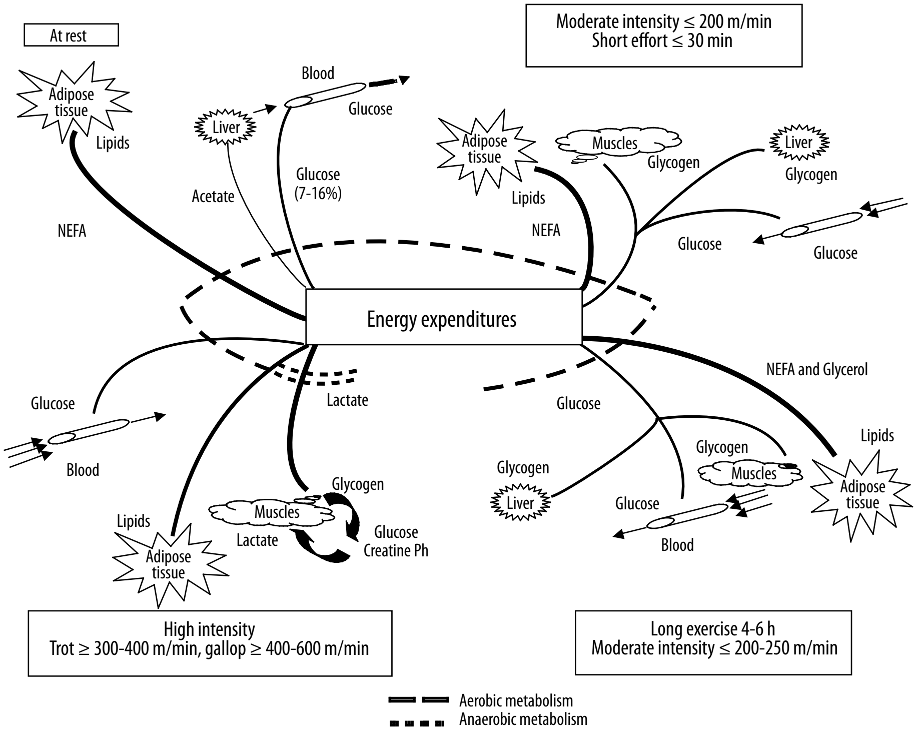

Figure 1.2. Energy sources used according to speed during exercise.

with the available digestive volume, which is itself related to the size of the animal. This is why intake capacity is also expressed relative to bodyweight: kg DM/100 kg BW.

Intake capacity of the young horse increases with its weight and size since the digestive tract, especially the large intestine, mostly develops from 12 to 18 months during the second pasture season following birth. But the intake capacity can be increased in the young horse managed to have a discontinuous growth model, i.e. compensatory growth, which occurs when a liberal feeding period follows a period of feed restriction.

Intake capacity in mares increases with the demands of lactation and gestation. During lactation intake increases rapidly following foaling. It will not limit milk production if the diet is liberal, even with forage based diets unless the forage is of very low quality (≤5% CP/g DM) or of straw, even if, in all cases, the ration is supplemented with concentrate feed. Intake is lower in gestation, especially during the last several weeks, and particularly if the forage is of mediocre quality, due to the pressure imposed by the developing foetus. Similarly the intake capacity of working horses increases with energy expenditure.

Intake capacity is subject to environmental factors. It increases with cold and decreases with heat. It decreases as well with stress induced by transport or changing physical or social environment. Intake capacity is also sensitive to nutritional balances, insufficient watering, protein supplementation and mineral deficiencies, or digestive problems induced by parasitism of food origin. Intake capacity is variable, averaging 20% among animals of the same breed, weight, receiving the same dietary regimen and producing the same performance. This variability may reflect differences in capacity and digestive efficiency and/or in regulation and metabolic efficiency.

In nutrition, the term feeding level is also frequently used to characterise intake by animals. Feeding level is expressed in reference to maintenance: either by feed intake in digestible organic matter (DOM) per kg $BW^{0.75}$ (32 g DOM/kg $BW^{0.75}$ corresponding to maintenance) or by energy intake expressed in UFC per kg $BW^{0.75}$ (0.0373 UFC/kg $BW^{0.75}$ corresponding to maintenance).

1.1.5 Water requirements

1.1.5.1 Requirements related to waste elimination: faeces, urine

The quantity of water lost in faeces varies from 7 to 9 l per day by a 400 to 500 kg horse at maintenance receiving a limited ration. The proportion of water in the faeces varies between 70 and 80% for diets high in concentrates and between 75 and 85% for high forage diets. The quantity of water excreted in faeces is, however, related to the indigestible components excreted. This explains why the quantity of faecal water is positively correlated with level of feeding and the quantity of cell wall glucides in the diet and negatively to their digestibility.

At maintenance the quantity of water lost in urine varies between 4 and 22 l per day in a horse weighing 400 to 500 kg. It is related to the quantity of metabolic waste eliminated by the animal. Urinary water excretion can also be related to food intake and digestion, to the level of protein in the diet especially when it is in excess of requirements, the quantity of urine eliminated by the kidneys and the intake of certain ions: Na, Cl, K. This is the reason why excessive consumption of lick blocks as well as molasses or potassium rich distillery by-products may induce polyuria in horses.

1.1.5.2 Requirements related to heat loss

The horse, as with other species, loses water in the form of vapour through the lungs and through the skin as perspiration; that is, water diffusion across the skin or by transpiration by sweat glands. The latter are well developed and efficient in horses, which are able to more easily maintain a constant body temperature than cattle or swine under conditions of excess heat production or elevated environmental temperatures.

Depending on measurement conditions (rest or work), the importance of water loss through the lungs and skin amounts to between 2 and 40 l per day; this latter figure reached under conditions of very intense physical activity. The predominant facture governing these losses is, in effect, heat production by the animal due, in the first case, to the production of muscle energy and secondarily to the quantity of food intake. The quantity of water evaporated appears to change linearly with the amount of identical work performed but to be greater when the work is more intense though the energy expenditure remains the same.

Evaporation also depends on the external environment: an increase in temperature results in an increase in heat loss and, therefore, an increase in water evaporation. The difference in water requirements between winter and summer, in temperate zones, is around 10 l for a horse weighing 400 to 500 kg. It is probable, however, that as in ruminants, the increase in water requirement is greater for a similar increase in temperature when the temperature is high.

1.1.5.3 Production related requirements

The daily requirements for water are not greater than 2 l for the products of conception at the end of gestation or in the weight gain of the developing foal, but may reach 15 to 30 l at the start of lactation and 5 to 10 l immediately prior to weaning. It appears, therefore that the water requirements of horses and the distribution of water among urine, faeces, evaporation and production are largely dependent on the physiological condition and activity of the animal. An example taken from the literature will help illustrate (Table 1.3).

These requirements depend on both the individual (coefficient of variation is frequently greater than 10% for horses receiving the same diet) and daily fluctuations (coefficient of variation over 30 days is between 20 and 25% depending on diet and season).

1.1.6 Meeting expenditures: feed intake and body reserves

1.1.6.1 Sources of nutrients

Organs and tissues meet their requirements necessary for the functioning and synthesis primarily through nutrients circulating in blood. Nutrients circulating in blood are of either endogenous or exogenous nature. Nutrients obtained directly from food digestion are from exogenous sources. They are available after absorption and/or conversion by the digestive tract or liver. Nutrients are in excess when compared to requirements after a meal. A portion is then stored in reserve in muscles (amino acids) or in fat (long chain fatty acids). Between meals the quantity of nutrients absorbed is below requirements. Endogenous sources are used to meet requirements; amino acids are derived from catabolism of muscle proteins and long chain fatty acids are mobilised from fat depots.

Table 1.3. Water balance in a 450 kg horse. Expired and perspired water has been calculated as the difference between total water intake and water excreted in urine and faeces. Metabolic water has not been taken into account. Diet: forage (25 to 50%) and concentrate (50 to 75%). (Adapted from Grandeau and Alekan, 1904).

Activity level	Resting	Work
Water intake (kg)		
feed	0.9	1.2
drink	16.3	23.3
total	17.2	24.5
Water excreted as % of water intake		
faeces	40.1	37.6
urine	37.4	27.6
expired and perspired	22.5	34.8

It is this dynamic equilibrium that assures requirements are met and a constant internal environment is maintained: i.e. homeostasis. Therefore, feed intake covers expenditures either in a direct and instantaneous manner after absorption or in an indirect and alternate manner from reserves.

1.1.6.2 Recommended feed intakes

The recommendations made in this book cover the recommended daily allowances to meet the needs of various categories of horses at different levels of production (Chapters 3 to 8). They concern mainly winter feeding as this is the easiest to quantify. The animals are assumed to be in good health and receiving a balanced diet. These feed allowances must permit the animals to reach expected performance levels that have been determined through a set of feeding trials relating actual attained performance to the nutrients consumed. But these intakes must also cover all or part of requirements according to the importance of the immediate needs or the envisioned techno-economic strategy. In every case envisioned the allowances will be completely covered in the mid-term: weekly (work: Chapters 6 and 8), summer/winter period (growth: Chapters 5, 6 and 8), production cycle (gestation, lactation: Chapters 3 and 8).

Young horses

Dietary allowances are designed to permit the animal to obtain the expected weight gain according to the category of horse as defined by breed and, systematically, sex and age (Chapters 5, 6 and 8). Positive and/or negative differences may be observed between expected and observed performance because of individual genetic potential since performance, when using recommended feeding allowances, represents the average of the population studied in the series of experimental trials, which resulted in the establishment of the relationship between feed allowances and performance. In another situation, the young horse during the winter, may undergo a lower growth rate than expected from the stated feeding allowances because of voluntary feed restriction. This may be compensated for during the summer, while on pasture, by more rapid growth, termed compensatory growth, due to a more liberal diet.

Lactating mares

We can identify 2 types of reproductive mares: mares destined to produce equine athletes (racing or sport horses) and mares destined to produce horses for pleasure or work (Chapter 3).

Expenditures of lactation increase immediately after foaling and reach their maximum during the 2nd month. Intake capacity also increases very rapidly. Mares are not limited in meeting their requirements for lactation and reproduction, even on diets based on good or average quality forage. Mares are usually bred during their first month of lactation. In the case of race or sport horse mares who foal during or at the end of winter, respectively, requirements are necessarily met in their winter rations and then at pasture. These mares are maintained in constant body condition. In contrast, mares of draft or leisure breeds are fed with economics in mind (reduced costs) and, in winter, receive limited quantities of stored forage (and concentrate feeds). Any deficit, mainly energy, is then met by mobilising body reserves. The mare rebuilds these reserves while on pasture in the summer. The mare must thus attain maximum body condition at weaning and optimal condition at foaling to assure viability and growth of her foal as well as a successful pregnancy following foaling (Chapter 3, Figures 3.10 and 3.11).

Horses at work

The equine athlete must, during a period of training reach an optimal body condition score of 3, while simultaneously attaining an optimal form in order to maximise performance (Chapter 2, Table 2.2). In leisure or draft horses body condition generally ranges between 3 and 3.5.

Requirements of working horses increase with intensity of work. Intake capacity also increases. It has few limitations even on good quality forage based diets (the athlete) or average forage quality (leisure or draft) with respect to meeting needs. The ration is always supplemented with concentrate in proportions varying from 10 to 60% of total dry matter intake. When the immediate (daily) requirements are very high, as in endurance horses, eventing or racing, horses will meet short term (daily) or medium term (following days) deficits by mobilising body reserves. These are restored over the days following a race or competition by means of the diet, which is provided in larger quantities even though, logically, work decreases after the competition. The amount of energy required to restore optimal body condition has been established (Chapter 2, Tables 2.4 and 2.5).

1.1.6.3 Expression of requirements and allowances

Feed components are transformed during digestion into nutrients that are absorbed from the digestive tract to be utilised by the tissues or secreted in milk. There are different losses at various stages, since feed constituents are not all completely digested. Nutrients circulating in blood are utilised by tissues but also result in the production of waste products; their efficiency of utilisation is, therefore, less than 1.

The nutritional value of feeds and recommended nutrients allowances are evaluated and expressed taking into account these physiologic and metabolic limitations:

In net energy: which represents the energy content of feeds minus all the digestive losses and metabolic waste. For practical reasons it is expressed in forage units (Section 1.3).

In total amount of true digestible nitrogen which represent the amount of dietary amino acids absorbed in the small intestine and amino acids synthesised by the microflora of the large intestine from residual dietary nitrogen. For practical reasons it is expressed in 'Matieres Azotées Digestibles Cheval' or Horse digestible crude protein (Section 1.4).

In quantities of minerals in feeds (contents); but the recommended allowances are much higher as losses and waste are taken into account (Section 1.5).

1.1.6.4 Body reserves: role and importance

Body reserves play a buffering role between the feed allowances and energy expenditure when intake is insufficient in the short or medium term. Body reserves are essentially composed of lipids localised in adipose tissues or fat and to a lesser extent between or in muscles.

The weight of adipose tissue has been measured by anatomical dissection after slaughter at INRA. The total weight of dissectible adipose tissue varies in light horses by a coefficient of 1 to 8 depending on the fattening state as determined by a condition score of 1 to 4.5, respectively, on a 0 to 5 scale according to the INRA-HN-IE method described in Chapter 2. This amount represents 2.5 to 12.9% of BW (Table 1.4). The weight of total dissectible adipose tissue (TDAT) can be estimated with good precision from a body condition score (BCS) with the aid of the equation developed by INRA:

TDAT (kg) = $5.868^{0.563}$ BCS R^2=0.990 n=20

The energy content (EC) of the carcass (muscles + total dissectible adipose tissue) is very high: it varies from 1 to 3 as the body condition score increases from 1 to 4.5 (Table 1.4). It can be estimated with good precision from the BCS with the aid of the equation:

EC (Mcal) = $1.901^{0.373}$ BCS R^2=0.993 n=20

A 500 kg light horse with an optimal body condition score of 3.0 or 3.5 will have total adipose depots representing respectively 6.1 and 8.1% of bodyweight. Energy content of these adipose depots and muscles varies from 559 to 645 Mcal of net energy.

Recommended feed intakes have the objective of attaining the optimal body condition score at key points in the production cycle or in the use of the horse (Chapters 3 to 8) because of the evaluation of variations in the energy content of the carcass. In practical rationing terms it is possible to establish the quantity of net energy, expressed as UFC, that it is eventually necessary to provide adjusted according to the situation (Chapter 2).

Table 1.4. Body composition and energy content of light horses (Martin-Rosset *et al.*, 2008).

Body condition score[1]	Bodyweight (kg)	Total dissectible adipose tissue[2]		Muscles (kg)	Energy[3] (Mcal)
		(kg)	(%)		
1.0	404.5	9.39	2.3	185.97	303.90
2.0	443.0	16.68	3.8	194.95	383.87
2.5	476.7	23.34	4.9	209.91	461.67
3.0	516.7	31.84	6.1	232.01	577.52
3.5	547.5	44.41	8.1	250.01	716.30
4.0	573.5	56.36	9.8	259.42	889.33
4.5	557.5	72.14	12.9	238.96	980.41

[1] Body condition score evaluated according to the INRA/HN/IE estimation (1997) (Chapter 2).

[2] Total dissectible adipose tissues (depots) = subcutaneous depots + internal abdominal cavity depots and external organ depots + intermuscular depots.

[3] Total energy content: dissectible adipose depots (subcutaneous + internal + intermuscular) and muscles (includes intramuscular adipose depots) measured in an adiabatic bomb calorimeter after drying and grinding.

1.2 Food intake and digestion

Horses are fed, as are all herbivores, largely on pasture and/or stored forage either natural (e.g. permanent pasture) or cultivated (e.g. rye grass) or partially on crop by-products and cereal straws. The quantity of energy that horses can obtain from forages offered free choice depends:

- On their ingestibility: that is the quantity that the animal can consume spontaneously.
- On their digestibility: that is the proportion of forage, more precisely of organic matter, that disappears in the digestive tract (Chapter 12). This can be quite variable as is indicated in the tables of composition and nutritional values of feeds (Chapter 16).

Forages for horses with increased requirements are supplemented by feeds rich in digestible constituents in order to balance diets from a nutritional point of view. Such feeds are rich in proteins and other intracellular constituents, such as fruits, grains, roots and their by-products. The provision of supplemental feeds also has an effect in the ingestion of forages. However, the proportion of forage in the diet should never be less than 20% in order to maintain normal behaviour in the confined horse and proper functioning of the digestive tract.

1.2.1 Feed intake

The horse, as with man and all animals, consumes food and water primarily to meet nutritional needs, but also to find a mental balance associated with sensory perception and a state of satiation. As well, the voluntary consumption of food varies with the weight and temperament of the animal. For an animal with specific needs, it also varies with physical-chemical characteristics of the feeds which influence their nutritional value and palatability. Finally, the horse's appetite is related to the organoleptic qualities of the feeds (palatability) and its living conditions, for example its maintenance in confinement.

To clarify the relative importance of these various factors we firstly examine the horse's feeding behaviour and its variations; then we detail factors related to the animal or to the diet influencing intake.

1.2.1.1 Feeding behaviour

Feeding behaviour of horses is different on pasture than when stabled. On pasture horses are free usually with companions and grass is always available. Feeding activities can be regulated largely by pasture availability, but also by environmental influences. In the stable, the horse is tied or in a stall and receives a ration the nature of which can be very variable; feeding activities are very much influenced by humans.

On pasture

The behaviour of horses on pasture has been well studied in both wild and domesticated situations (Chapter 10). Daily grazing time is more than 12 hours, since the horse spends much time masticating. Grazing extends into the night representing 20 to 50% of eating time and can occupy 30% of the nocturnal period. When in herds, grazing occurs in 3 to 5 cycles separated by rest periods in adults

(18 to 20% of the diurnal period) mostly standing. The beginning and end of the grazing cycles is related to sunrise and sunset and is controlled by the dominant animal.

Grazing behaviour on pasture is under environmental influence (climate, social, etc.) and the availability of grass. In temperate zones the duration of grazing increases slightly in fall when compared to summer, but generally it is a greater proportion of the diurnal period, which shortens with the advancing season. In autumn, the grazing cycles merge and are extended into the night. In summer, the duration of grazing decreases with high temperatures and the accompanying presence of insects. In temperate zones grazing times reach maximums at a temperature of 18 °C. Increased humidity and intermittent light rain lengthens the duration of diurnal grazing. In contrast, this is diminished by violent rain and/or winds. All grazing disturbances reported for the following night or days have a magnitude that varies with the hardiness of the genetic type. An increase in grazing pressure or animals per hectare appears to lengthen the duration of diurnal grazing. In contrast, associating horses with cattle in a ratio of 1:1 or 1:3 with the same total grazing load expressed as kg bodyweight per hectare, does not increase diurnal grazing time in horses, but seems to limit the number of grazing cycles (fusion).

Feeding behaviour of horses at pasture also varies with the choice of available plant species (Chapter 10). Rye grass, meadow fescue, red fescue generally are preferred; Kentucky bluegrass, orchard grass (or cocksfoot) and common bentgrass, timothy, and white clover to a lesser degree; foxtail, woolly velvet grass and especially brome grass are not sought out. Mixtures are always more desirable, especially when they contain white clover. In complex vegetation mixtures (natural meadows), food choices depend on land use and the available quantities of grass. In meadows maintained in natural condition the horse will choose the most accessible plants (height) if the nutritional value is sufficient or may combine grazing of both high and low vegetation in order to ensure coverage of energy needs (high growth) and protein (low growth vegetation) (Chapter 10).

At the trough

Total mastication time on a forage-based diet provided *ad libitum* varies from 9 to 13 hours in horses vs 14 to 16 hours (eating + rumination) in cattle or sheep. It is quite variable from day to day among horses and even within the same horse. There is no established correlation on an individual or daily basis between eating duration and the quantity eaten. The horse has an average of 11 to 12 meals per day. A large meal follows each daily feeding, when there are only two daily feedings, the two big meals represent 40% of total eating time.

Eating at night is important and can account for a third of eating time (Figure 1.3). Preferred night time eating is in the early part of the night. Three to four cycles of sleep are interspersed between meals and can account for 32 to 40% of the night.

While eating, prolonged chewing of forage is accompanied by a copious flow of saliva (an average of 4 l of saliva/kg of hay), but can vary depending on the nature and dry matter content of the feed. As well the unit duration of eating (the time required to ingest one kg of dry matter) is increased on average 40 to 55 min/kg of hay dry matter. Eating one kg of hay requires 3,000 to 3,500 chews. It is swallowed in 80 boluses.

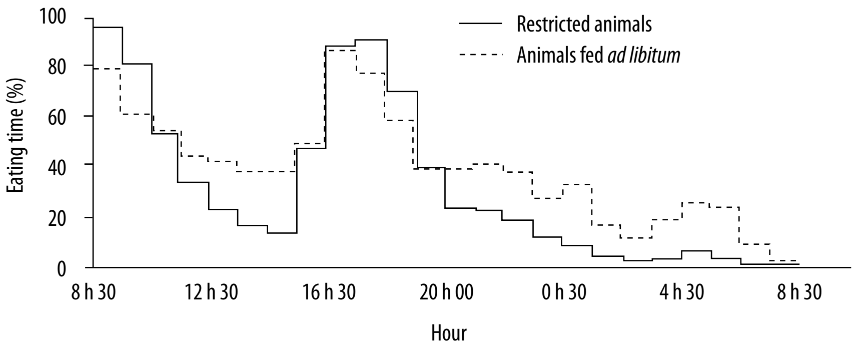

Figure 1.3. Eating time distribution during day and night in horses. The diet consists of hay provided *ad libitum* and supplemented with 2 kg of oats divided into two meals (Doreau, 1978).

When the quantity of feed offered is limited, total eating time is significantly reduced, but eating speed varies very little. The duration of nocturnal eating is considerably reduced (Figure 1.3). Meals that follow the distribution of food are prolonged to the detriment of repeat, smaller meals, and represent two-thirds of total eating time. Under these conditions it is understood that the horse fed limited quantities will not have the important nocturnal feeding activity, which may be important in producing a psychic equilibrium, even if the precaution is taken of providing the greater proportion of forage in the evening meal.

The mastication of a kilo of concentrate or cereal grains, no matter what their presentation form, only requires 10 to 20 minutes and 800 to 1,200 chews. Time is probably longer when horses are fed *ad libitum* with either grains or pelleted feeds. Ponies eat their daily rations in 10 to 20 meals more in the day than at night, with a total eating time of 6 to 8 hours. It appears that the animal fed *ad libitum* with concentrate diets to which it is accustomed regulates its intake in its own circadian rhythm and, probably, does not depend on the nature of the feed. Such diets produce behavioural problems, such as wood chewing, flank biting or coprophagy.

Feed preferences are measured by simultaneously presenting two or more feeds to horses. The history of the animal plays a significant role in its choice. Therefore, when choosing between long and chopped hay the horse will prefer the hay to which it is accustomed. It is the same when comparing different grains. However, it appears that softer pellets are preferred to hard. The addition of sweet products, such as sucrulose or molasses, significantly increases the palatability of feeds. The determination of concentrations of salt, bitter or acidic solutions at which rejection will occur shows that foals' response is similar to sheep. The outcome of all these studies indicates individual variability is significant.

1.2.1.2 Feed quantities ingested

The dry matter intake quantity for a given animal in a given physiological situation depends on three categories of factors:

- The characteristics of the animal which can be identified by the term intake capacity; this is first determined by energy expenditures and is increased with work, milk production, growth, etc.; it also depends on the animal's appetite, which is related to size and state of health.
- Feed characteristics which can be identified by the term ingestibility; it can be assessed in the mouth (organoleptic characteristics or palatability), digestive (bulk) or metabolic (energy balance).
- Environmental conditions, climatic (temperature,), social (dominance,), parasitism.

Forage intake

Forage intake is between 75 and 115 g DM/kg $BW^{0.75}$ or 1.5 to 2.0 kg DM/100 kg BW for green grass forages for the horse at maintenance. Stage of maturity and the number of cuttings does not influence intake (Figure 1.4). This is the reason that no significant relationship between intake and plant cell wall content (crude fibre or NDF – ADF) can be used to predict intake of hay or forages.

Intake of grass silage is less than that of fresh forage or hay. It increases with dry matter content from 40 g DM/kg $BW^{0.75}$ (0.8 kg DM/100 kg BW) for direct cut silage at 22% DM without preservatives to 90 g DM/kg $BW^{0.75}$ (1.8 kg DM/100 kg BW) for wilted silage at 36% DM. Intake of wilted silage or moist hay stored in wrapped round bales is higher yet: 108 g DM/kg $BW^{0.75}$ (2.3 kg DM/100 kg BW) for moist hay at 50% minimum DM. Intake of whole plant corn silage varies from 50 to 80 g DM/kg $BW^{0.75}$ (1.0-1.6 kg DM/100 kg BW) if the DM content ranges from 25 to 40%. Intake of straws is limited and very variable: 40 to 95 g DM/kg $BW^{0.75}$ (0.8 to 2.0 kg DM/100 kg BW) respectively for straws from cereal cultivation or from forage plants.

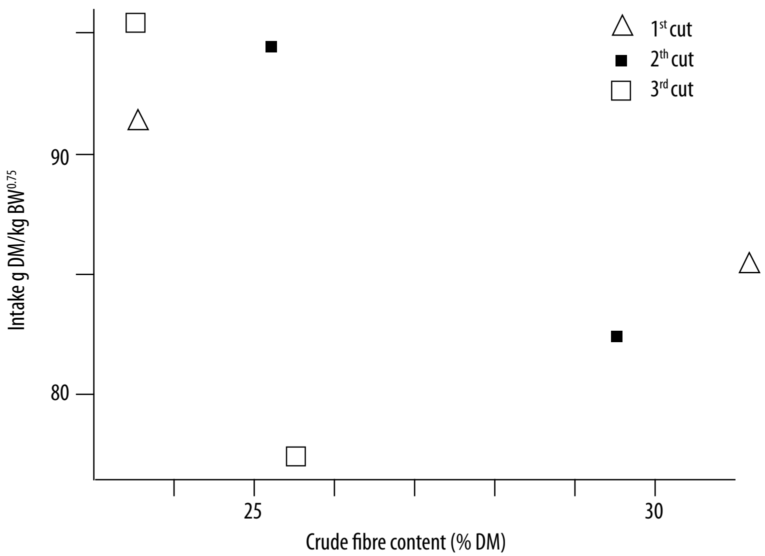

Figure 1.4. Intake of fresh natural meadow grass or from various cuttings in the horse at maintenance (Chenost and Martin-Rosset, 1985).

Intake capacity

Intake capacity varies according to physiological stage and state in interaction with type of forage. In the young horse dry matter intake increases as bodyweight increases, but less rapidly. It is closely related to metabolic weight but equally to size (Table 1.5). The variation is always in the same direction no matter what forage is offered: fresh grass silage, wilted grass silage or maize silage, but intake level depends on forage type because of their specific ingestibility.

There is little change in intake capacity in mares during gestation (74 to 95 g DM/kg $BW^{0.75}$) (or 1.4 to 1.8 kg DM/100 kg BW) since her abdominal space is limited by the development of the gravid uterus, which puts pressure on the large intestine. After foaling intake increases dramatically in the early weeks: 125 g DM/kg $BW^{0.75}$ (or 2.5 kg DM/100 kg BW) to a maximum of 160 to 170 g DM/kg $BW^{0.75}$ (or 3.0 to 3.5 kg DM/100 kg BW).

In working horses forages are usually provided in limited quantities with the exception of endurance horses during certain periods (between competitions, periods of recuperation or at the start of training).

1.2.2 Digestion

The horse is an herbivore: the digestive tract is characterised by a relatively small stomach and a well-developed intestine consisting of 2 principal parts: the small intestine and the large intestine (Figure 1.5A).

1.2.2.1 Intestinal transit times

On average food is in the digestive tract of the horse for 30 hours, mostly in the large intestine (24 hours on average). Total transit time shows little change with level of feeding (limited vs *ad libitum*) in the horse at maintenance (Table 1.6). In contrast, it is shorter and somewhat longer in the lactating and gestating mare respectively (Table 1.6). Transit time is shorter in light horses than in draft horses (Table 1.6).

Table 1.5. Intake capacity of young light breed horses fed hay based diets (50 to 80%), straw (10 to 25%) and concentrate feeds (10 to 25%) (adapted from Bigot *et al.,* 1987).

Age (months)	Average weight (kg)	Intake	
		per 100 kg BW (kg DM)	per kg $BW^{0.75}$ (g DM)
6-12	190-310	2.3-2.6	97-108
18-24	290-310	2.2-2.3	100-104
30-36	515-525	2.1-2.2	100-105

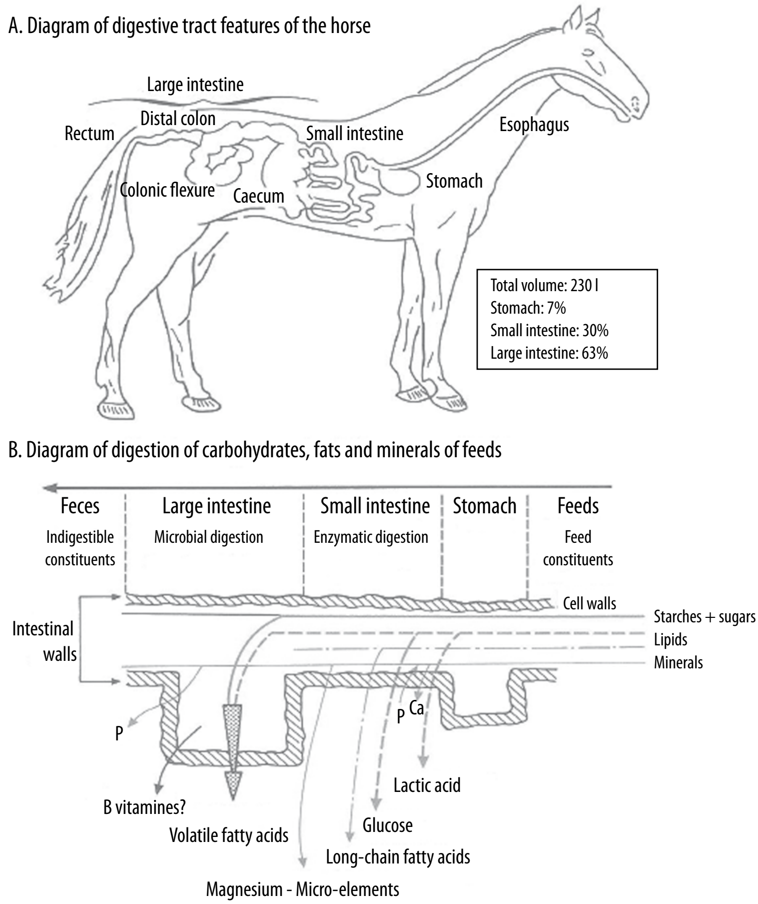

Figure 1.5. (A) Digestive tract and (B) digestion in the horse.

Table 1.6. Transit times through the digestive tract of horses: effects of feeding level, physiological state and breed (Miraglia *et al.,* 1992).

Breed	Sex	Feeding level	Average transit time (h)
Light breeds	geldings	maintenance (1.1)	25.2
		ad libitum (1.5)	25.9
	open mares	maintenance (1.2)	36.5
		ad libitum (1.7)	31.5
Draft	gestating mares	*ad libitum* (1.7)	20.9
	lactating mares	*ad libitum* (2.5)	22.2

1.2.2.2 Digestion in different compartments

In the mouth food undergoes mastication and the important addition of moisture through salivation (insalivation) (40 to 50 l/d), which is indispensable for swallowing and proper digestion further down the tract. The stomach is relatively small (approximately 15 to 18 l). It only fills to two-thirds capacity but empties continuously as food is consumed. It closes firmly at the end of a meal at the gastric-oesophageal sphincter, which prevents the possibility of vomiting.

Gastric digestion involves only a limited fraction of the feed components, especially in forages. Protein begins hydrolysis due to the presence of pepsin in gastric juice (10 to 30 l/d). Cellulose and certain other components (e.g. finely milled bran) undergo the beginning of digestion. In contrast, the digestion of other dietary constituents is very limited: carbohydrates with the production of volatile fatty acids (only 0.4 g/l, which amounts to 90% of the acetic acid produced) and/or lactic acid; or nothing (fats or minerals). Stomach pH varies from 4 to 6 depending upon the time-schedule of the meal. As a consequence microbial proliferation and implantation are not inhibited.

The small intestine is very long (16 to 24 m), but food passage takes only 3 hours. It is the site of continuous bile secretion (5 l/d) even though the horse does not have a gall bladder, pancreatic juice secretion (7 l/d) and periodic intestinal secretions (5 to 7 l/d) that are responsible for the digestion of all food constituents (Figure 1.5B).

Sugars (glucose, fructose, saccharose), lactose and proteins are largely digested here by digestive enzyme action to provide the animal with energy nutrients (glucose, long chain fatty acids, lactic acid), or proteins (amino acids) (Figure 1.5B). Most of the non-protein nitrogen, especially urea, is absorbed well before it arrives in the large intestine and joins the urea already in the blood. 70 to 95% of sugars in forage and concentrates and of the starch in cereals are digested in the small intestine if the feeding level is below 2, with the exception of whole maize kernels. Proportions are higher if starch has been exposed to technological treatments: grinding of barley and maize, flaking, expansion, extrusion, but part of the starch may escape enzymatic digestion if intake per meal exceeds 200 g/100 kg BW. Where proteins are concerned the amount digested in the small intestine varies from 30% for low digestible, cell wall rich forages, to 60 to 90% for seeds, grains and their by-products. Digestion of fats and oils is high at 80% in the small intestine while their true digestibility in the total tract is 90 to 95%.

With the exception of phosphorus, mineral absorption occurs in the small intestine. Calcium absorption is from the anterior portion of the small intestine while magnesium, sodium, potassium and the micro-elements are absorbed throughout the length of the small intestine. Phosphorus is partially absorbed at the end of the small intestine but mainly in the colon (Figure 1.5B).

The large intestine, the most voluminous compartment (180 to 220 l) of the digestive tract in horses, is always full. It contains the residues of enzymatic digestion of feeds, which have an average residual time of 24 hours. It also contains an important and very active microbial population, which transforms, through the process of fermentation, the undigested food residues from the small intestine into nutrients.

The microbial population of the large intestine consists of between 5 and 7×10^9 bacteria per g of digestive contents depending on the compartment (caecum or colon). The species of bacteria most frequently identified are *Streptococcus, Bacteriodes,* and *Lactobacillus,* while protozoa are less numerous (10^2 to 10^3/g). The density of cellulolytic bacteria is 6 times greater in the caecum than in the colon, which is the inverse of their respective volumes, 30 and 180 l, respectively. Proteolytic bacteria are from 2 to 8×10^5 per g of digestive contents. Physico-chemical conditions, i.e. pH of 6 to 7, oxidation-reduction potential, anaerobic, temperature and mixing are favourable to the fermentation of feed components that have escaped enzymatic digestion. Plant cell wall and cellulose degradation results in the production of volatile fatty acids: 3 g/l on average in the caecum and colon. This mixture consists of acetate (70-75%), propionate (18-23%) and butyrate (5-7%). These are absorbed from the two compartments and meet 30 to 70% of the energy requirements of the horse depending on the composition of the diet, in particular the proportion of concentrate. 15 to 30% of nitrogenous material of feed origin is added to endogenous nitrogenous materials arriving in the large intestine where they are degraded into amino acids and ammonia, which are reutilised for the synthesis of microbial proteins or recycled via the urea cycle after absorption in the form of ammonia. The bacteria are capable of synthesizing 2.5 and 0.8 mg of protein/g of dry digestive contents/hour in the caecum and colon respectively. Amino acids of dietary or microbial origin are only marginally absorbed from the large intestine. In contrast the excess ammonia is absorbed then converted to urea by the liver. Urea quantities produced increase with the quantity of protein ingested. Urea is simultaneously excreted in urine through the kidneys, in digestive contents, by simple diffusion across the wall and by the intermediary of digestive secretions (saliva). It is hydrolysed to ammonia by microbes in the large intestine similarly to amino acids of food or endogenous origin. The nitrogen of urea can thus be reabsorbed either directly in the form of urea or marginally in the form of amino acids or, lastly, as ammonia produced by the final degradation of microbial protein. The horse is capable of excreting close to 50% of endogenous urea in its intestine through direct diffusion from blood: or 90 g of urea, which is the equivalent of 250 g of protein per day. Urea of endogenous origin present in the large intestine is about 50% utilised. Exogenous urea in various forms (urea, biuret, di-ammonia phosphate) will equally be used by the horse with an efficiency of 25%.

The microflora of the large intestine can synthesise all of the B group vitamins, consequently, supplementation of these vitamins is not recommended.

1.2.3 Intake quantity regulation and expression

1.2.3.1 Mechanisms and important factors

Intake adjustment is a function of energy expenditure, affected partly in the short-term, that is at the level of a meal or a day, and partly on a long term basis, which will permit the horse to correct an inadequacy between energy needs and supply. The long-term intake is controlled by the central nervous system, the hypothalamus, where an appetite control centre is located in the lateral part and a satiety centre in the ventro-medial part.

In the short term the organoleptic qualities of feeds apparently are important to horses. They prefer feeds having a sweet taste (e.g. carrots). With forages horses appear to prefer long form presentation vs chopped. Horses prefer in descending order silage, wrapped silage and hay all cut at the same stage of maturity, but no clear explanation of this has been given.

Limitation of feed intake due to the effect of obstruction is not normally a concern. The relatively small stomach capacity does not keep the horse from eating. Effective motility of the stomach, small intestine and the caecum due to the effect of eating certainly contributes to eliminating blockage of any compartment by a meal. In contrast an excessive volume of ingesta in the colon will bring about a reduction in intake but only with low quality forages (e.g. straw). The narrowing of the curve of the pelvic colon may be the cause of the slowdown.

The end products of digestion may cause a delay or stoppage of eating. Glucose and certain volatile fatty acids (acetate, propionate) may produce this effect, but the results obtained from studies are contradictory. The location of receptors for these metabolites is not well known. In contrast, the metabolism of glucose and fatty acids can produce a signal to commence eating again after a period of satiety.

Over the long term, weeks or months, horses can more or less regulate their intake to adjust to their energy requirements depending on whether they are at maintenance or in production. At maintenance the adjustment takes place over a very long term, more or less effectively depending on the nature of the feeds provided (Figure 1.6).

A condition of excessive fatness causes a significant reduction in hay consumption (Figure 1.6: phase 3). In contrast concentrate feed consumption is always higher than that of hay regardless of a high state of fatness or growth. The adjustment, therefore, is not perfect.

In contrast, this adjustment is more effective when the horse is even partially in production (Figure 1.7). The young horse of 1 to 2 years of age, fed with the same hay supplemented with two levels of concentrate feeds can make up 90 to 100% of a moderate difference in diet energy density, through the amount of dry matter ingested. However, similar growth will not be attained if energy intake is different. However, the young horse is not capable of compensating through increasing dry matter intake if the difference in diet energy density is changed by feeding cereal straw.

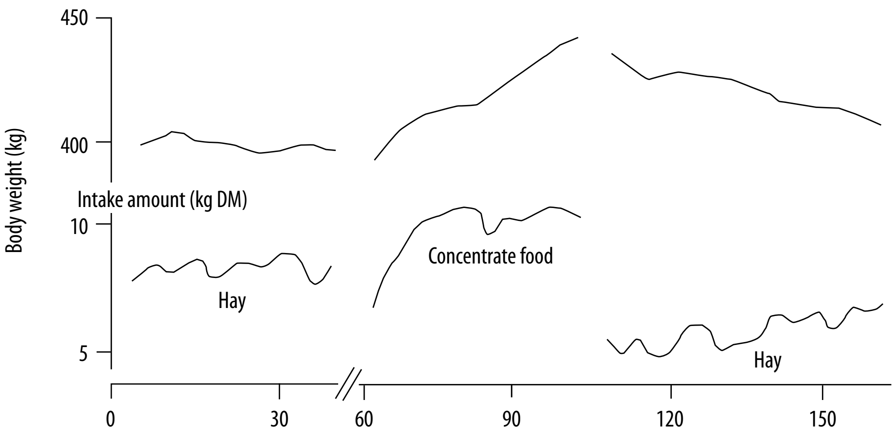

Figure 1.6. Relationship between feed consumed and the body condition of the horse (Meyer, 1980).

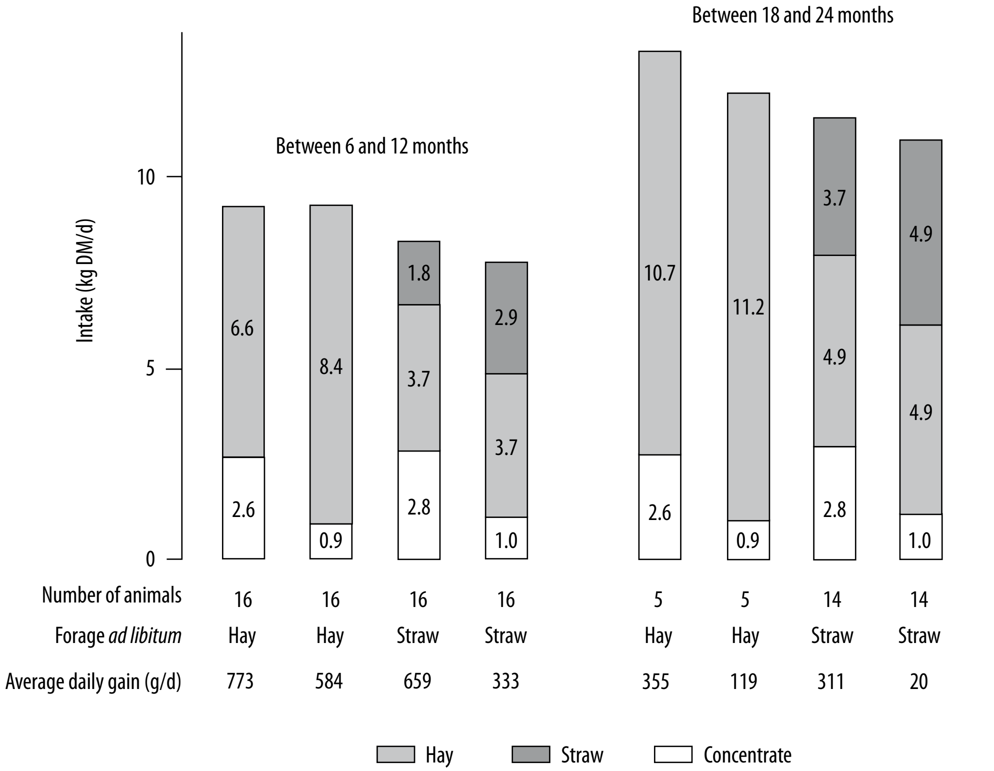

Figure 1.7. Effect of amount of concentrate feed intake and type of forage on dry matter intake by draft horse foals (Martin-Rosset and Doreau, 1984).

1.2.3.2 Diets containing 75% or more forage

The vegetative stage of given forage is the principal factor influencing digestibility but not its ingestibility in horses, with the exception of very poor forages (≤5% total protein content (CP)/DM). But it is possible to have differences in ingestibility of the same forage, harvested at the same stage but preserved by different methods, such as silage, wrapped bales, or wilted.

The quantity of energy obtained by a horse in production depends on the energy digestibility of the diet (energy value) and its protein content (% DP/DM). When requirements increase, the horse is capable of increasing intake in an attempt to meet these requirements: the lactating mare consumes more forage than the dry mare. The lactating mare also consumes more forage during the first few months of lactation than at the end. The actual performance, growth of the foal or milk production of the mare, for example, will be directly related to energy intake.

1.2.3.3 Mixed forage – concentrate diets: substitution of concentrates for forages

Diets for horses in production are always supplemented with concentrate feeds to allow them to achieve desired performance and meet the corresponding requirements. For young horses, (lactating) mares and certain working horses (endurance), diets with a forage base are usually fed *ad libitum*.

When the quantity of concentrate feed in the ration increases by x kg of dry matter, forage intake decreases by y kg of dry matter (Figure 1.8). The rate of substitution (S) of concentrate for forage is termed the y:x ratio, which gives the reduction in forage consumption per kg of concentrate dry matter. Observed values in the young horse and mare vary between -0.3 and -2.4 as a function of the nature (silage, hay, straw) and quality of the forage (nutritive value) (Figure 1.8 and Chapter 2).

One observes that with the young horse:

- The quantity of total dry matter intake continues to increase with silages or wilted hay with a high nutritional value (of S<1), as a result, the intake of nutritional components increases, which is the desired objective for animals with high requirements that have high intake capacity. It will be noted that substitution is only linear for the forages having the most limited nutritional value (maize silage with <30% DM) when compared to others (maize silage with >30% DM). The observed result is the same if one compares grass silage (<30% DM) with wilted silage (50% DM). In the latter case it means that there is a threshold beyond which the total dry matter intake and therefore the nutrient intake, increases more slowly.
- The total dry matter intake decreases linearly in hays with S>1, thus the nutrient intake decreases as well.

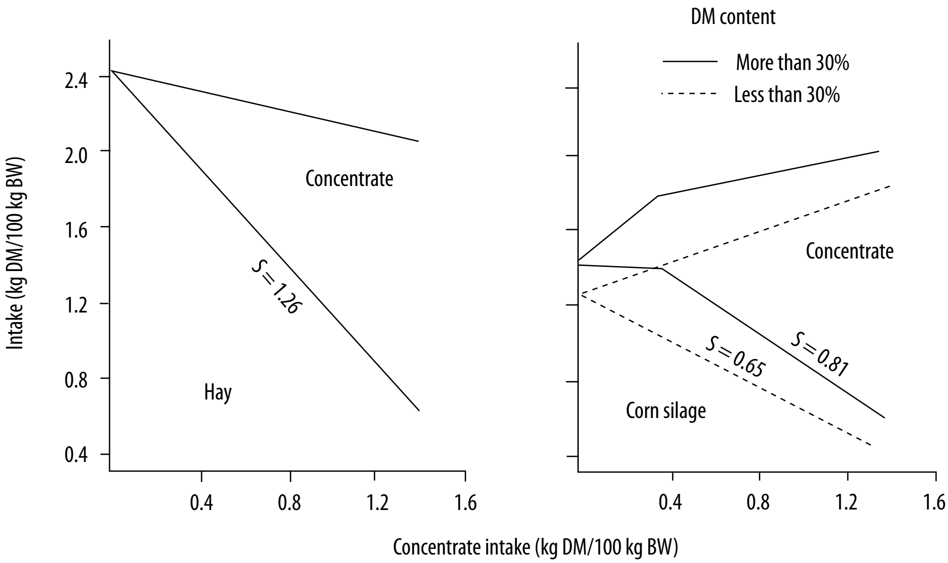

Figure 1.8. Influence of quantity of concentrate feeds on the quantity of forage and total dry matter intake in young horses 6 to 12 months of age. S = substitution rate (Agabriel *et al.*, 1982).

In the lactating mare the forage:concentrate substitution rate varies from -1.2 to -2.4, respectively, in hay or straw based diets supplemented with concentrate varying from 20 to 50%.

1.2.4 Water intake

Animals try to adjust their water intake to meet their requirements. Daily variation in the amount of water in an organism is very low. Ingested water comes from two sources:

- Water from feeds: the water content of dry forages and concentrates varies between 10 and 15%, but may be 85% for green grass and close to 90% for forage beets. In addition, nutrient catabolism results in the production of metabolic water. The catabolism of 100 g of carbohydrates, lipids and proteins results in 55, 107, and 41 g of water, respectively. A horse at maintenance (which catabolises all available metabolisable nutrients) consuming 10 kg of hay will therefore produce 2 to 3 l of metabolic water.
- Drinking water: this amount supplements the water provided in the feed to meet total water requirements. It has been shown that horse fed with the same alfalfa, green or dry, consume 30 or 2 litres of water in the forage, but 18 to 40 litres through drinking. The total quantities consumed were very close.

To determine the quantities of water necessary to meet the horse's requirements it is useful to relate them to dry matter intake. Both are essentially linearly related as energy and water requirements vary largely in the same direction. For animals at maintenance, water requirements related to dry matter are independent of bodyweight. However, for working horses or lactating mares water requirements increase faster than the need for dry matter (Chapter 2, Table 2.7).

When water is always available, horses drink more than 80% of total daily consumption in the hours following feeding. Watering when not permanent, for example when water is distributed in buckets, must be provided with each feeding.

1.3 Energy nutrition

1.3.1 Introduction

Until the late seventies energy value of feedstuffs and requirements of equines were using systems designed for ruminants before the Second World War. Following feeding experiments carried out in Scandinavia to determine substitution value of feedstuffs in ruminants (Fjord and Hanson), studies using calorimetry conducted by Kellner in Germany and by Armsby and Forbes in USA resulted in the development of two families of systems for evaluating energy value in ruminants across the world. One is based on net energy (NE) for fattening, whereas the other one is using total digestible nutrients (TDN). In both family systems a single energy value is assigned to each feed, but it was agreed that all the feedstuffs between themselves had the same relative value for maintenance, lactation, and fattening (Breirem, 1969). Then those systems were implemented for equines following metabolism trials, feeding experiments or field observation carried out with equines, largely in Europe (France: Grandeau, Muntz, 1880-1904; Germany: Kellner, Wolff, Zuntz, 1880-1911; and Scandinavia: Jespersen, Axelsson, 1930-1940) and in the USA (Morisson, 1930-1940) using different units. Net energy value was used and expressed either in starch equivalent in Germany (Kellner and

Fingerling, 1924), the Netherlands (Frens, 1949), United Kingdom (Watson, 1949) and Switzerland (Crasemann and Schurch, 1949) or in barley feed unit in Denmark (Jespersen, 1949), Scandinavia (Axelsson, 1949) or in oat feed unit in the USSR (Popov, 1946). In France, the NE values of feedstuffs was calculated according to a method derived from Armsby's proposals by deducting from the feed metabolisable energy content, the energy losses associated with feed intake, digestion and nutrient metabolism (Leroy, 1954). The NE values of feedstuffs were expressed using the feed unit, the NE content of one kg standard barley, as in the Scandinavian system. During the same period the TDN system was developed and proposed by Morisson (1937) in USA.

In the late seventies and early eighties two original systems were laid down for equines using experiments carried out with equines. One is based on digestible energy (NRC, 1978) and derived from the TDN system. This system has been developed in 1989 and ultimately refined in 2007. In this system the energy value of feedstuffs is only depending on chemical composition (CP and/or ADF) of feeds. Two equations were proposed in 1989 and again in 2007. These equations are based on digestibility trials carried out using total faeces collection. One is dedicated to dry forages and roughages, pasture, range plants or forages fed fresh and the other one is devoted to energy feeds and protein supplements. It is established for forages that there are large difference of organic matter digestibility (OMd) between classes of forages (Martin-Rosset *et al.*, 1984, 1996, 2012c). The same figure has been pointed out for concentrates (Martin-Rosset, 2012). OMd is much more accurately predicted when using equations dedicated only to major classes of concentrates (cereals grains, cereal by-products, oils seed and legumes seed by-products, legumes seeds) than when using a single equation for all concentrates. Residual standard deviations of specific equations for each class of forages or concentrates vs general equation for all forages or concentrates are always on average below 3.0 points OMd and over 6.0 points OMd, respectively, and as well R^2 are always on average over 0.90 and lower than 0.75, respectively (Chapter 12). The differences of energy value of feeds rely mainly upon discrepancies of energy digestibility. But those differences rise also after conversion of DE value into ME and then NE value. Indeed, it has been established that DE and NE values of average grassland hay (33% CF and 10% CP/DM) represent 67% and 48% of DE and NE value of barley, respectively. In the DE system it is admitted too that the efficiency rates of metabolisable energy for maintenance and lactation are in each situation constant, whatever the characteristics of the feedstuffs, to establish requirements of horses. Using this system, the energy value of forages is overestimated in respect of that of concentrates, and as a result, the requirement too. But rationing is working when the proportion of concentrates is high in the diet, which is the routine situation in USA, as pointed out by Martin-Rosset (2001), conversely to the calculations of Hintz and Cymbaluk (1994). This system is used throughout North and South America, Australia, New Zealand and Japan and in some European countries (Germany and United Kingdom).

However, Germany provided a new general equation for predicting DE of feedstuffs based on digestibility trials of diets carried out using AIA markers (GEP, 2003; Zeyner and Kienzle, 2002). It has already been established that digestibility coefficients using AIA method are higher for all nutrients, but not uniformly, compared to coefficients determined using total faeces collection, which is the reference method (Fuchs *et al.*, 1987; Miraglia *et al.*, 1999). In addition, it is expected that all digestive interactions between nutrients of the diets are cancelling each other out, which is not entirely true. This general model was derived from primary partial equations of Zeyner and Kienzle (2002) using the same data file. Unfortunately, there was some evidence of a deviation in the predicted DE from the experimental DE when using the general model of GEP 2003) which is consistent with the weak variance coefficient of the model: R^2=0.39 (Zeyner and Kienzle, 2002). In addition no comparison was carried out to determine DE content predicted with the general model proposed by GEP (2003) and with the conventional method, e.g. calculation of the weighted DE of rations from individual DE of feeds which composed the diets included in the data base, or with an independent data base. So far this model does not have any advantages over the NRC equations.

Germany is now moving to the ME system established in horses from the prediction of renal energy losses and methane energy losses determined in horses by regression analysis to nutrients (Kienzle and Zeyner, 2010). In this system, energy value of feedstuffs is only depending on chemical composition of diets (CP, essential amino acids (EAA), CF and NFE). It is expected again that all digestive interactions between nutrients of feeds are cancelling each other out as far as the data file comes from digestion and metabolism trials carried out only with diets. There is only one test of the validity of the model using feeding experiments with exercising horses (Schüler, 2009). So far there is not yet an advantage to use this single equation to predict energy value of feedstuffs and then carry out rationing, except in field conditions to check the energy content of diets.

The other system is based on net energy of feeds for maintenance (Jarrige and Martin-Rosset, 1984), because in horses as in ruminants or pigs the methane and energy losses and the efficiency of metabolisable energy utilisation depend on the proportions of digestion end-products and the biochemical pathways. More than a century ago, Wolff *et al.* (1877) stated that the maintenance DE requirement of horses was 15% higher with 75% hay than with 75% concentrate diet. Furthermore, the results of many feeding trials carried out with draft horses in Germany by Wolff *et al.* (1887a,b) and in France by Grandeau and Alekan (1904) showed that the DE requirements for maintenance and work was 25% higher for hay than for cereals. On these bases a NE system for work was established: the NE content of feeds was calculated from their digestible nutrient contents and corrected for the crude fibre content. It ranged from 117 for maize, 100 for barley to 44 for grass hay (Wolff and Kreuzhage, 1895). In the thirties, Fingerling (quoted by Nehring and Franke, 1954) showed that the efficiency of ME utilisation by horses for fattening, as measured by the carbon-nitrogen balance, was higher for starch and groundnut oil (80%) than for sucrose (72%) and pure cellulose (58%). It ranged from 73-75% for cereals to 35-52% for hays and 32-38% for straw. Later on, these results were confirmed by Hoffman *et al.* (1967), Willard *et al.* (1979) and Kane *et al.* (1979). Similarly, the efficiency of ME for maintenance (K) as determined by indirect calorimetry balances was 20% lower with a Lucerne-hay than with an 80% barley diet (Hintz, 1968). Thanks to this knowledge the new NE system proposed by INRA in 1984 was extensively developed using digestion and metabolism experiments and then validated using long term feeding trials with different types of equines (mares, young and exercising horses) (Julliand and Martin-Rosset, 2004, 2005; Miraglia and Martin-Rosset, 2006; Saastamoinen and Martin-Rosset, 2008). The frame of this new system was officially presented at the 1993 EAAP meeting in Copenhagen (Denmark), at the 1993 ENPS Symposium in Gainesville (FL, USA), at the annual 2000 KER meeting in Lexington (KY, USA) and the 2004 EWEN meeting in Dijon (France). Collaboration with Dutch scientists was set up. A NE system was elaborated in the Netherlands deriving from the French system, but adapted to the specific conditions of the country (CVB, 1996, 2004; Ellis, 2004). A working group, called 'Feed evaluation and nutrient recommendations for horses' composed of Nordic countries (Norway, Denmark, Island, Finland and Sweden) was mandated to find out a common basis and to adapt the French UFC system (Austbo, 2004). The main limitation of the final decision to adopt the French system is the lack of data derived from feeding experiments with horses to perform recommendations for the different types of horses and breeds in each country. So far, Denmark is still using Scandinavian Feed Unit, whereas Norway, Finland are still using the Fattening Feed Unit and Sweden is using ME system. Both systems are based on digestibility trials values obtained with cattle. The USSR use an Energy Feed Unit equivalent, so called oat feed unit, based on the system established by Kellner, but which derive from experiments with horses (Memedekin, 1990). The French system is increasingly used in Belgium, Italy, Portugal and Spain. Discussion is opened with other European countries, such as Poland and Romania.

The French system has been refined subsequently in 1990 and ultimately in 2012 thanks to the new results obtained mainly at INRA, and of course in the literature, to improve the accuracy of the estimate of the NE value of feedstuffs, of horse requirements and of rationing. Hence, the next step in this chapter is to give a full statement of the INRA system, where NE is expressed in barley feed unit so called Horse Feed Unit (UFC, or Unité Fourragère Cheval in French). We will refer to Section 1.2 Digestion to outline the main figure used for evaluating the true energy value, e.g. net energy expressed in UFC. We will also provide the main basis of energy requirements expressed in UFC. The feed allowances in UFC are displayed in the following Chapters dedicated to each type of horses (Chapters 3 to 8).

1.3.2 The use of feed energy

1.3.2.1 Different stages of feed energy use

Food use by animals is manifested by the various digestive and metabolic processes of the body, by the losses at each stage, which decreases the gross, or initial, energy (GE) in the food (Figure 1.9).

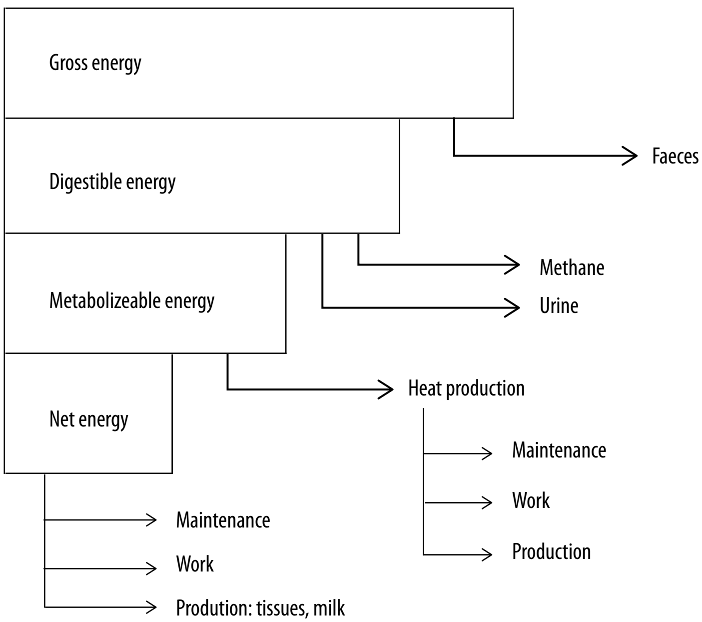

Figure 1.9. General diagram of energy use in the horse.

The organic constituents of feeds (Chapter 12) are not completely digested; some part is therefore excreted in the faeces (FE). For forages from 30 to 65% is excreted (high quality forage vs cereal straw) and for concentrate feeds rich in starch (cereals) from 10 to 30%. Digestible energy (DE) is therefore the difference between the gross energy of the feed (GE) and the energy lost in faeces (FE). The energy digestibility is the relationship between the digestible energy (DE) and the gross energy (GE) of the feed:

$DE = GE - FE$ $\qquad$ $dE \text{ coefficient} = DE/GE$ or $dE = (GE - FE)/GE$

Feed digestibility ranges from 30 to 90% respectively for straw and maize grain. Digestibility is the major factor determining the energy value of feeds. Feeds subsequently undergo fermentation during microbial digestion in the large intestine with a loss of energy on the form of methane gas, which in horses represents 2% of the gross energy. A fraction of the end products of food digestion is not used by the organism. It is primarily eliminated in the form of urea in urine. Urinary energy (UE) represents on average 4% of gross energy. It is more important when protein intake is high.

Feed energy potentially utilisable by the organism is the metabolisable energy (ME):

$ME = GE - FE - G_{CH4}\,E - UE$ or $ME = DE - G_{CH4}\,E - UE$

The proportion of metabolisable energy in digestible energy (ME/DE) varies primarily with the characteristics of the feeds: 78 to 80% for oil meals, 84 to 88% for forages, 91% for straw, and 90 to 95% for cereals. In contrast, the metabolisable energy of feeds is considered constant regardless of the function for which it is used.

The final products of food digestion are utilised by the tissues to meet the energy costs of maintenance and production. This is the net energy (NE). However, a fraction is lost in the form of extra heat (EH). This corresponds to the cost of tissue function, to the energy cost of synthesis and the energy cost of eating.

The extra heat and, in consequence the net energy, depend partly on the characteristics and the proportion of end products of digestion (or post-absorption nutrients) and partly on the functions for which they are used (maintenance, growth, lactation, work, etc.). The transformation of metabolisable energy to net energy is carried out with certain efficiency: $K = NE/ME$, which never reaches 100%. It varies partly with the function for which the energy is used and partly according to the end products of digestion and, therefore, feed composition.

1.3.2.2 The metabolism of energy substrates

Sources

Energy substrates used by the organism come partly from nutrients derived from food digestion and partly from body reserves (especially lipids) when the animal is underfed. The amount of total energy supplied by end products of digestion of forages and concentrates was established from their content in feeds and their true digestibility in different digestive compartments (Table 1.7).

Table 1.7. Estimation of the proportion (%) of absorbed energy provided by principal end products of digestion and their efficiency of use at maintenance (Km) (Vermorel and Martin-Rosset, 1997).

	Glucose+ lactate	Volatile fatty acids	Long-chain fatty acids	Amino acids	Km[1]
Maize	63	21	8	8	0.800
Barley	58	27	5	10	0.785
Oats	48	26	15	11	0.778
Good meadow hay	12	71	5	12	0.654 [2]
Alfalfa hay	13	62	5	21	0.660 [2]
Poor meadow hay	9	82	3	6	0.610 [2]

[1] Km = yield of metabolisable energy in net energy at maintenance.

[2] Includes a correction for the cost of eating forage.

Glucose plus lactate provides 11 to 56% respectively of the total energy absorbed from forages and concentrate feeds respectively. Volatile fatty acids represent 71 and 25% respectively of the total absorbed energy from the same categories of feeds. These percentages vary with the relative proportions of the principal volatile fatty acids: 60 to 76% for acetic acid, 14 to 25% for propionic acid, and 10 to 15% for butyric acid. Long chain fatty acids from feeds provide 3 to 10% of total energy ingested, or 15 to 20% if the diet is rich in feed lipids or the animal mobilises fat from body reserves. Amino acids represent 10 to 13%.

Substrate use within the organism and efficiency of utilisation

Only a portion of the absorbed energy is utilised. The various end products of digestion are absorbed from the digestive tract compartments in which they are produced. Intestinal epithelium uses a fraction for its own energy expenditures and for its own synthesis. Caecal epithelium metabolises a small amount of butyrate to ketone compounds. With the exception of long chain fatty acids (>C14) which are transported by the lymphatic system, almost all the absorbed products enter the blood of the portal vein and are carried to the liver. The liver captures a portion for its energy metabolism and product synthesis: glycogen from glucose, glucose from propionate, proteins from amino acids and triglycerides from long chain fatty acids. In contrast there is little metabolism of acetate and butyrate into ketones (Figure 1.10).

During the absorption phase the end products of digestion carried to the liver far exceed the liver's capacity to metabolise them. They enter the general circulation and are utilised by peripheral tissues. Those that are not oxidised as a source of energy are used for the synthesis of glycogen, lipids and proteins. Muscle tissue stores glycogen synthesised partly from glucose and increases protein synthesis. Adipose tissue synthesises triglycerides from fatty acids, glucose, acetate and butyrate. The quantity of energy stored in the form of triglycerides, primarily in lipid vacuoles in adipose tissue, is much more important than reserves in the form of liver and muscle glycogen. This storage is stimulated by the secretion of insulin, which is greatly increased by food intake.

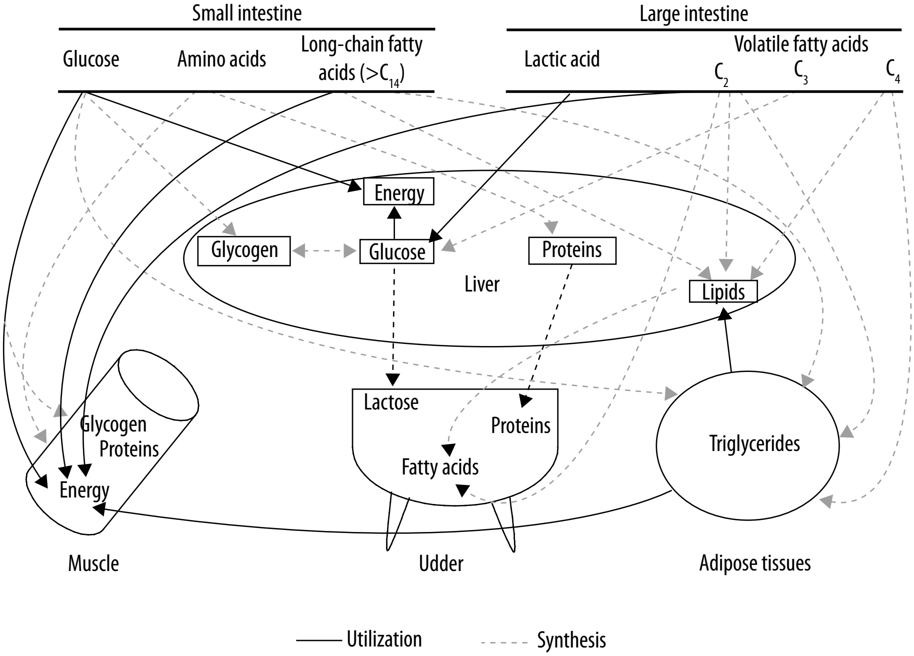

Figure 1.10. A simplified diagram of the metabolism in the horse.

At maintenance net energy of a substrate can be compared to the quantity of free energy (ATP) which is used during its catabolism to cover the different components of the cost of maintenance. This quantity of free energy unfortunately is not measurable, being released in the form of heat it is just added to the heat lost in the utilisation of metabolisable energy. When the animal is fasting the required free energy is taken from body reserves, essentially lipids. This is why the net energy of a feed for maintenance is defined nutritionally, by the quantity of energy from body reserves that can be spared when the feed is consumed by the fasting animal. Measurements made in horses show that the yield of metabolisable energy for maintenance varies with the composition of the diet as is the case in ruminants and other species. At maintenance the horse primarily uses, as a source of energy, acetate and long chain fatty acids coming from body lipids (non-esterified fatty acids) and, to a lesser extent, glucose and even amino acids with efficiencies of 80, 63, 85, and 70%, respectively. The yield (or ratios) of utilisation of feed energy and, of course, the diets, is going to depend on the balanced yields of various nutrients from the digestion of the feeds and therefore their chemical composition. It has been established that it varies from 80% for maize to 60-62% for hays and 43-45% for straws. In other words, the yield varies in the same direction as digestibility and therefore with the concentration of metabolisable energy, and in an inverse direction to the plant cell wall content (content of crude fibre).

In work, the energy recovered in the form of external mechanical work (locomotion, pulling) only represents a fraction of the energy expended above maintenance (Figure 1.11). First of all the efficiency of free energy production (ATP) is limited: 30 to 40% from amino acids and glucose, respectively, acetate being intermediate. Then the efficiency of ATP to produce (external) mechanical work varies

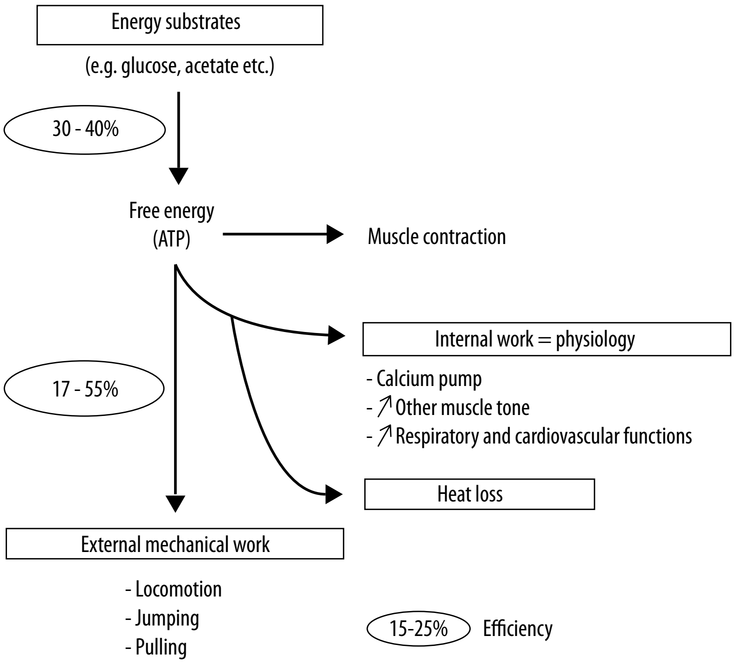

Figure 1.11. Utilisation of energy for work.

from 17 to 55% depending on the intensity. Finally, about 25% of the energy expended by skeletal muscle in muscle contractions is used to produce various physiological processes (internal work). This expenditure of free energy for the various processes is accompanied by a loss of metabolisable energy, such as heat, representing 75% of total metabolisable energy loss. The net efficiency of energy use for work varies from 15 to 28%. In the light of practice, it has been shown from the end of the 19th century that energy from forages is used much less efficiently for work than energy from grains (25% relative value). These trials have shown differences in the efficiency of energy used for work from various feeds studied, which are similar to those observed for maintenance. This is quite understandable insofar as expenditures related to work will be met by glucose, fatty acids and acetate in different proportions depending on the intensity of effort.

In gestation, the conceptus (foetus + products of conception: membranes, uterus, placenta) essentially uses glucose (Chapter 3). Glucose provides for the synthesis of glycogen reserves, certain non-essential amino acids, glycerol and some fatty acids. The weighted efficiency of use of various nutrients for the growth of foetal tissue and other products of conception depends also on the chemical composition of the feed and the diet, but is low (25%).

During lactation the mammary gland absorbs large quantities of glucose from the blood for the synthesis of lactose and other milk constituents, and probably for a source of energy. The udder also absorbs acetate, β-hydroxybutyrate and amino acids with an extraction efficiency of 20 to 40%. Acetate provides 20% of the energy. It is the principal precursor of milk fatty acids; additional precursors are essentially coming from plasma lipoproteins. The weighted efficiency of use of various nutrients for lactation depends as well on the composition of the feeds and diets but is high and approaches that of maintenance (65%). The efficiency of use of energy for lactose synthesis is high. Fatty acids arising from the digestion of fat sources in feeds are not metabolised and are used very efficiently in the synthesis of milk fat. The efficiency of energy use for the synthesis of milk proteins is probably high.

The quantity of proteins synthesised in the growing animal is much more important than in the adult. Synthesis for tissue growth added to that for cell renewal is more rapid than in the adult. The quantity of protein synthesised is greater than that which is retained in the tissue. It varies in the same direction as the latter and, therefore, as weight gain. It is positively related to both the protein and energy provided, both having additive effects. A large proportion of the amino acids absorbed is used for the synthesis of proteins, the remainder is catabolised to glucose or energy for tissue functioning. But protein synthesis is energetically expensive as the efficiency of utilisation of energy for growth and even more for fattening is limited and also very variable depending on the proportion of glucose and acetic acid available to the organism. The efficiency of utilisation of energy for growth and fattening varies in the direction as that for maintenance, but is much lower (35 to 55%). The efficiency of feed energy for building body reserves is much lower than for using them.

Utilisation of feed metabolisable energy

The energy cost of eating foods and the functioning of the digestive tract is higher for forages than for concentrate feeds, and for forages high in lignified plant cell walls than for young forages. Undigested plant constituents in the small intestine are fermented by the microbial population of the large intestine with the production of volatile fatty acids, microbial mass, methane and the heat of fermentation. The additional energy expenditures due to eating and digestive tract functions and the loss in the form of heat of fermentation are added to the extra heat produced, which increases the differences in feed net energy value. Energy losses in the metabolism of nutrients by tissues and organs; that is in the transformation of metabolisable energy to net energy are greater for the volatile fatty acids produced from the digestion of forages than for those associated with glucose utilisation, fatty acids and amino acids from the digestion of concentrate feeds.

Feed metabolisable energy is used more efficiently for maintenance (from 54 to 76%), and lactation (65%), than for growth and fattening (35 to 55%) and for work (15 to 28%). The most recent and complete data available are for the maintenance condition. In addition, the energy expenditures for maintenance represent 50 and 90% of total energy expenditure in the lactating and pregnant mare, respectively, from 60 to 90% in the growing or fattening horse and finally from 70 to 80% in the working horse. It is for this reason that the maintenance situation has been chosen as the reference point for estimating feed net energy values. Moreover, the efficiency of metabolisable energy use for maintenance and work, in both cases, depends on free energy: ATP produced by the oxidative catabolism of nutrients. In both situations, feeds have the goal of replenishing body reserves for late use in the form of ATP to meet the expenditures of daily maintenance as well as those related to work effort. Variations in the yields of different nutrients, and therefore feeds, are the same for maintenance and work, even if the absolute yield values are different (Figure 1.12). The efficiency coefficient (K) of feed energy utilisation at maintenance (m) is indicated as Km.

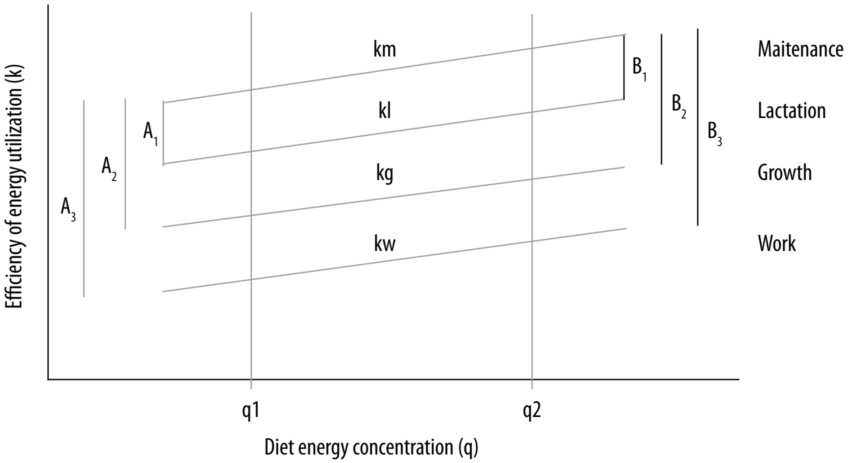

Figure 1.12. Relative variations in the efficiency of energy utilisation for various functions.

1.3.3 The 'Unité Fourragère Cheval' system

1.3.3.1 Evaluation of the values of feed energy

The energy value of a feed is the quantity of net energy of a kilo of this feed that contributes to meeting the expenditures for maintenance and production of an animal. The value is measured in kilocalories (kcal) per kilo of feed. For practical purposes: substitution between feeds, it is related to a reference feed, one kilo of average barley at 87% dry matter and expressed in Unité Fourragère Cheval (UFC):

$$\text{Energy value of a feed (UFC)} = \frac{\text{Net energy (kcal) of a kilo of feed}}{\text{Net energy (kcal) of a kilo barley}}$$

The net energy value of a kilo of barley at 87% DM is established as follows:

- Gross energy (GE): 3.85 Mcal/kg as fed
- Digestible energy (DE): DE = GE × dE; DE = 3.08 Mcal/kg as fed — dE = 0.80
- Metabolisable energy (ME): ME = DE × ME/DE; ME = 2.87 Mcal/kg as fed — ME/DE = 0.931
- Net energy (NE): NE = ME × Km; NE = 2.250 Mcal/kg as fed — Km = 0.785

One UFC is then the energy value of one kilo of standard barley for maintenance: 1 UFC = 2,250 kcal. The net energy value of different feeds is calculated using the general basic approach described in Table 1.8. The details of the method, including the set of equations used in the intermediate steps are presented in Chapter 12.

1.3.3.2 Expression of requirements and recommended energy allowances

Requirements and recommended energy intakes are expressed in UFC for the various functions: maintenance, mating, pregnancy, lactation, growth, fattening and work.

1.3.3.3 Calculation of recommended energy allowances

The energy allowances corresponding to a production function are added to maintenance costs, eventually taking into account the makeup of body reserves (Chapters 3 and 8) in order to determine total energy allowances:

Total allowances = maintenance allowances + production allowances ± Δ (body reserves)

Requirements were established using two methods: the measurement of physiological expenditures and the efficiency with which they are met by energy intake (factorial method) and feeding trials (global method) (Table 1.9). Maintenance requirements are proportional to the size and therefore the metabolic weight of the animal. The energy expenditure varies considerably with the behaviour, breed, sex (Table 1.1) and environment (Section 1.1.2).

Table 1.8. Basic approach for calculating the UFC value of feeds.

Gross energy: GE		
Digestible energy: DE = GE × energy digestibility coefficient (dE)		
Metabolisable energy: ME = DE × ME/DE		
ME/DE (%) = 84.07 + 0.0165 CF – 0.0276 CP + 0.0184 CG[1]		
Net Energy: NE = ME × Km_c: efficiency of utilisation of ME for maintenance		
Km =	+ forages	variables for 4 different equations:
	+ cereals – legume grains	chemical composition
	+ cereal by-products	± digestible elements
	+ meals	(Chapter12)
	Km corrected for the cost of eating forages	
Km_c	Km_c = Km – Δ Km	
	Δ Km = -0.20 CF (in %) + 2.50	
	or Δ Km = -0.14 (76.4 – dE %)	
Value UFC/kg of feed		
$UFC = \frac{ME \times Km \text{ (concentrates) or } Km_c \text{ (forages)}}{2,250}$		

[1] CG = cytoplasmic carbohydrates.

Table 1.9. Efficiency of metabolic utilisation of metabolisable energy and requirements for different functions.

Maintenance	
Efficiency (%)	50-80
Requirements (UFC/d/kg BW^{75})	0.0373 [a] – 0.0392 [b] – 0.0410 [c]
Gestation	
Efficiency (%)	25
Requirements (UFC/d/100 kg BW)	0.06 – 0.28
Lactation	
Fat content (g/kg)	10-20
Efficiency (%)	65
Requirements (UFC/kg milk)	0.23-0.29
Growth	
Fat content of empty bodyweight gain (g/kg)	100-180
Requirements (UFC/kg of liveweight gain)[d]	1.3-2.4
Work	
Efficiency	15-25
Requirements (UFC/hour)	0.2-4.5

[a] Draft horse.
[b] Light horse.
[c] Thoroughbred.
[d] Period: 6-12 months.

Production requirements were established from either the composition of the product and the efficiency of metabolic utilisation of metabolisable energy, when it was known from the factorial method (pregnancy, lactation), or in relating the quantity of UFC consumed to the measured performance during feeding trials (growth, fattening). For work, the requirement was established by measuring oxygen consumption while working. In all cases allowances have been measured through the set of feeding trials conducted to investigate the effects of different variables. These allowances may correspond, or not, to requirements depending on production strategies (for example: winter feeding of draft mares) or to the immediate (daily) importance of requirements that can only be met over an extended time (week) (for example: work – endurance).

1.3.3.4 Comparison with the other (energy) systems

The UFC system is an empirical model for predicting NE value of feeds for horses. It does not pretend to give the true energy value of feeds but to provide a closer approach than either DE or ME systems. It is now well established that methane and urine energy losses and utilisation of ME for maintenance or fattening vary with diet composition as in other species. In the DE system proposed by NRC, the energy value of forages and protein rich feeds is overestimated by about 15% for cereals and by-products, 25-30% for oil meals and 30-35% for hays, whereas that of feeds rich in starch is underestimated (Vermorel and Martin-Rosset, 1997).

The aim of the ME system proposed by Germany (Kienzle and Zeyner, 2010) is designed to overcome the limits of a previous model designed by GEP (2003) for predicting feeds' DE values. Unfortunately, this new proposal also fails. The initial weaknesses of the original DE model are still included in the ME model. ME values of feeds with a high or low fibre content for instance, are still overestimated and underestimated, respectively. Interactions between feed components, diet composition and feeding level are all expected to cancel each other out, which does not happen. The predictive equation cannot yet be applied extensively to individual feeds displayed in feed tables. In addition, the ME model has not yet been validated with a sufficient number of feeding trials carried out with different equine livestock. For instance, the results obtained with mares, growing and exercising horses fed a large range of diets and achieving a large range of performance in long term feeding trials should be compared with the results using only factorial calculated requirements of horses of different physiological status. This would provide a validation starting point.

The NE system is based on the metabolic utilisation of nutrients for ATP production. The efficiency of nutrient energy and feed ME utilisation for maintenance were both validated by indirect calorimetry and feed experiments carried out at INRA in equines (1980-1997). The main limit in the accuracy of the UFC system is now focused on the estimate of the percentage of absorbed energy supplied by the principal nutrients. However, errors in estimation have relatively limited effects on Km. For instance, in the case of wheat bran, a 20% underestimate of the volatile fatty acids (VFA) supply results in a 0.4% unit error in Km that is a relative error of only 0.5%.

Using Km to predict the energy value of feeds for horses in various physiological situations certainly causes errors in lactation and growth estimates. However, it is established in ruminants that the ratio Km/Kl is relatively constant whatever the feed (Van Es, 1975). The situation could be similar in horses and the NE values of feeds should be close for maintenance and lactation (Figure 1.12). Furthermore in lactating mares, energy requirements for milk yield account for only about 50% of total energy requirements. The differences in efficiency of ME utilisation for maintenance (Km) and for fattening (Kf) or growth (Kpf) are certainly higher than for lactation (Kl) (Figure 1.12), especially in the case of forages, but requirements for growth account for only 10 to 20% of total energy requirements in light breeds and 20 to 40% for heavy breeds. The relative variations of the efficiency of ME utilisation for maintenance (Km) and for work (Kw) carried out under aerobic conditions, which is the most prevalent situation (Chapter 6, Figure 6.10), are very similar to the chemical composition of feeds (when the chemical composition of feeds is taken into account) (Figure 1.12). Indeed, the relative energy value of feeds is close (e.g. substitution value) for maintenance and work as energy is mainly used for ATP production in both situations as it was noted early on by Armsby (1922). Under anaerobic conditions, instantaneous Kw is likely affected during extreme exercise and post exercise recovery. But work requirements account for only 5 to 35% of total energy requirements over the long term. When compared with other systems the validity of the NE system was tested at INRA throughout many feeding trials (1972-2006) with mares, growing and working horses fed a large range of diets (hays, grass silages, maize silages, haylages, hays and straws supplemented with different proportions of various types of concentrates fed at different feeding levels according to expected performance).

The more analytical approach to calculating NE values of feedstuffs and diets enables the introduction of new knowledge in the successive steps of energy utilisation without any large modifications in the structure. For instance, a correction of Km in respect of energy cost of eating, evaluated recently at INRA and which decreases NE value of forages, has been introduced easily into the framework. The ME content of feedstuffs is calculated from their chemical composition, energy digestibility and the ME/DE ratios, which makes it possible to account for the gross energy content and energy digestibility of specific feeds. NE value of feeds can be estimated very easily by routine laboratories as criteria, analytic methods and tools (equations) are proposed for the main categories of feedstuffs used in horse diets. Feed tables provide the means to compare the value of feeds, to point out their modification by technological treatments and to calculate and formulate efficient and least cost rations and compound feeds respectively.

The energy value of feedstuffs is expressed in UFC, because feeds are more frequently compared in terms of substitution value than in absolute NE values from the feeding or business point of view in Europe. But one would be more precise with absolute NE values, using NE values of feedstuffs displayed in INRA feeds tables (Chapter 16). Tables of recommended feed allowances could be easily converted to NE (expressed in Mcal) as suggested earlier in 2000 at the Feeds Manufacturers Conference in Lexington, USA (Martin-Rosset, 2001).

1.4. Protein nutrition

1.4.1 Introduction

Until the late seventies nitrogen value of feedstuffs and requirements in equines were using systems designed in ruminants before the Second World War. The terminology used to express the nitrogen value of feedstuffs as well as requirements across the world was confusing and clarification is required.

Nitrogen (N) content of feedstuffs is determined using the Kjeldahl method and expressed as crude protein (CP). Crude protein comes from N content multiplied by a conventional factor 6.25. At the end of the 19th century two groups of N components were identified: true protein and soluble nitrogen (non-protein nitrogen: NPN), which were separated using salts of heavy metals such as copper hydroxide (Stutzer reagent). A debate about the method of separation of the two N fractions ensued.

Apparent digestibility (d_a) is the well-known criterion used to determine N digestion in the total digestive tract in ruminants and monogastrics. Nitrogen value of feedstuffs (and requirements) was evaluated and expressed either in digestible true protein (DTP): $[(CP - NPN)] \times d_a$ or in digestible crude protein (DCP): $CP \times d_a$. DCP was shortly implemented in USA (Armsby, 1922; Morisson, 1937), whereas digestible true protein, suggested by Kellner (1911) and Kellner and Fingerling (1924) was extensively used in Europe primarily in equines (Hanson, 1938; Jespersen, 1949; Crasemann, 1945; Ehrenberg, 1932; Leroy, 1954; Larsson *et al.*, 1951). It was pointed out that digestible true protein underestimated, in ruminants, the nitrogen value of feedstuffs whose NPN content rose, because ruminants are able to use urea. DCP terminology became increasingly common in Europe for ruminants and consequently for equines (Nitsche, 1939; Axelsson, 1943; Leroy, 1954).

DCP has been extensively quantified using digestibility trials in ruminants and to some extent in horses thanks to the studies carried out in Europe (Germany: Wolff *et al.,* 1877-1890; France: Grandeau and Muntz, 1880-1904; Martin-Rosset *et al.*, 1978-1985 and others; Scandinavia: Olsson *et al.,* 1949) and in USA (Darlington and Hersberger, 1968; Fonnesbeck, 1968, 1969, 1981; Fonnesbeck *et al.*, 1967; Hintz *et al.*, 1970-1980; Lathrop and Boshstedt, 1938; Lindsey *et al.*, 1926 and others). All these data were subsequently compiled in tables devoted to equines: Kellner (1911), Lavalard (1912), Morrison (1937), Schneider (1947), NRC (1978, 1989, 2007) and INRA (1984, 1990 and 2012). It has been clearly established in both animal species that digestibility of nitrogen is strongly linked to N content and DCP content can be predicted from CP content using linear relationships. Until the late seventies DCP was promoted in equines in USA (NRC, 1978) and in Europe from the late fifties when DCP was adopted in ruminants.

DCP content evaluates N amount × 6.25 which is apparently digested in the total tract of equines. DCP content does not accurately evaluate the amount of amino acids which is absorbed and subsequently the true nitrogen value of feedstuffs. DCP evaluation does not discriminates in the end-products of N digestion the proportion of amino acids, which is absorbed in the small intestine, and ammonia, which is produced during the digestion of residual N feeds in the large intestine, either in excess by microbial population or supplied by the degradation of bacterial protein, whereas nitrogen:energy ratio is not optimal for microbial protein synthesis (Santos *et al.*, 2011); stated that there is no significant absorption of amino acids in the large intestine (Martin-Rosset and Tisserand, 2004). Hence two new systems were proposed in USA (NRC, 1989) and in France (INRA, 1984). NRC proposed to evaluate and express nitrogen value of feedstuffs (and requirements) using CP content because of the lack of information regarding DCP (digestibility determination) and amino-acids availability (amount absorbed). This system has been confirmed by NRC in 2007. In France, INRA proposed a new system in 1984 which has been confirmed in 2012. In this system the nitrogen value of feedstuffs depends on the amount of protein truly digested in the small intestine and the amount of nitrogen used by the microbial population to meet its own requirements, using digestion coefficients determined in each digestive compartment in fistulated horses using a mobile nylon bag technique (Macheboeuf *et al.*, 1996; Martin-Rosset *et al.*, 2012a,b). The system was named MADC (Matières Azotées Digestibles Cheval in French and Horse Digestible Crude Protein in English). This system allows a better comparison of feedstuffs when rationing equines.

A new emerging system is actually under discussion in Germany (Zeyner *et al.*, 2010). It is stated that amino acids of feedstuffs are only absorbed in the small intestine, whereas amino acids provided by turnover of microbial population cannot be absorbed in the large intestine. The system is based on the concept that neutral detergent insoluble CP content (NDICP: insoluble protein) of feedstuffs and the corresponding soluble CP (NDSCP: soluble protein) discriminate between cell wall protein (N-bounded) and cytoplasm cell protein. The NDICP fraction cannot be broken down by auto-enzymatic digestion in the foregut, whereas NDSCP can be digested by animal-host enzymes in the small intestine. AA profiles of NDICP and the corresponding NDSCP would be similar within a given feed. Using a meta-analysis of data of the literature there is a good positive relationship between small intestinal digestible crude protein (sidCP) and NDSCP intake. That would indicate that NDSCP fraction of the feeds would indirectly estimate the part of CP which would be available for auto-enzymatic digestion. This system is walking towards the same direction as the INRA system, but it does not take care about the own N requirements of the microbial population (Section 1.4.4). Hence, it underestimates the nitrogen value of feeds.

The French system has been refined subsequently in 1990 and ultimately in 2012 thanks to the new results obtained mainly at INRA (mainly new digestion trials carried out in the years 1995-2000 using fistulated horses) and of course in the literature, to improve the accuracy of the estimate of the MADC value of feedstuffs, of horse requirements and of rationing. Hence, the next step of this Chapter is to give a full statement of the MADC system. We will refer to Section 1.1.2 to outline the main figure used for evaluating the nitrogen value. We will also provide the main basis of nitrogen requirements expressed in the MADC system. The feed allowances in MADC are displayed in the following Chapters dedicated to each type of horses (Chapters 3 to 8).

1.4.2 Protein metabolism

1.4.2.1 Body proteins

Proteins make up 21 to 22% of the fat-free body mass in the adult horse, or 17 to 19% of the animal's weight depending on the degree of fatness. A little more than half will be in the muscle mass (myofibril proteins, sarcoplasmic, etc.), almost 30% in the form of collagen in connective tissues, the skeleton, the skin and appendages, 7 to 8% in the wall of the digestive tract and liver, and 3% in blood. The 'standard' protein mass of the animal will be composed of 66% cellular proteins, 30% collagen and 4% keratin. There is no specialised tissue for storage of excess protein as there is adipose tissue for energy. Enzymes, hormones are the functional proteins present in very small amounts.

1.4.2.2 Synthesis and degradation of body proteins

All proteins are constantly being degraded and replaced but at very different rates. Enzymes, hormones, fibrinogen, blood lipoproteins have a very short lifetime and are very often degraded as they complete their mission. Intestinal epithelial cells are renewed very rapidly with a lifetime of 2 to 3 days. It is similar for the liver proteins. Muscle fibre proteins are renewed at a variable rate depending on their category, but on average about 1 to 2% per day. In the adult animal collagen is renewed most slowly. The growth and replacement of appendages (hair) which have keratin as the basic protein is similar.

The quantity of protein synthesised daily is in the order of 15 g/kg $BW^{0.75}$ or 1,600 to 2,500 g of protein from bodyweights ranging from 500 to 800 kg. The source of amino acids utilised for protein and functional compound synthesis is the amino acids absorbed after enzymatic digestion of dietary proteins as well as amino acids derived from the degradation of body proteins.

On a metabolic weight basis, the quantity of protein synthesised daily by a growing animal is much greater than in an adult animal, up to 3 times as much in the first weeks of life. Synthesis for body growth must be added to that needed for replacement of proteins previously synthesised, (measured in an animal in zero nitrogen balance), which is more rapid than in an adult animal. The total quantity of protein synthesised is much greater than the incorporated protein. It is positively correlated with the latter, and, in general, with weight gain. It is correlated with protein availability and energy intake with both having additive effects. The best information has come from muscle protein studies. Maximum incorporation of muscle protein requires a high level of protein synthesis, but, paradoxically, it is also associated with rapid protein degradation.

Protein metabolism is under hormonal control. Insulin, growth hormone, androgens and oestrogens all have anabolic action, while glucocorticoids are catabolic.

1.4.2.3 Amino acid metabolism

The muscle mass contains more than half of each free amino acid while the blood has less than 5%. The digestive tract walls and liver are intermediate. The total pool of free amino acids is replenished by amino acids absorbed from the digestive tract and by amino acids produced in the degradation of proteins, which may be utilised on site or transported to other organs in the blood. The total pool of free amino acids is small, of the order of 1% of body proteins. It is much less than the flux of amino acids that is used each day for protein synthesis (from 10 to 100 times in the animal at maintenance). The length of time amino acids remain free is short but variable.

Blood provides the transport medium of amino acids and their exchange between intestinal epithelium, liver, muscles and kidneys. Plasma concentration of free amino acids is affected by all the factors that influence the contributions or uptakes by tissues and organs. The plasma content of free amino acids increases a few hours after a meal is eaten, especially if the meal is rich in proteins. This increase is moderated by the significant uptake by the intestinal wall and liver. The muscle mass is in a positive balance. After about 10 hours following a meal there is a decrease in the synthesis of proteins and protein degradation increases in the entire organism. The liver continues to be in positive balance, but all peripheral tissues are in negative balance. The muscles undergo a net loss of all amino acids, especially alanine and glycine, which transport nitrogen and carbon from muscles to the liver, digestive wall and kidneys. During the fasting period between two meals the plasma amino acid concentration reaches a minimum and then begins again to increase rapidly. Essential amino acid concentration in plasma reflects protein quality.

Amino acids that are not utilised for synthesis are rapidly degraded. Their carbon skeleton is oxidised directly or utilised by the liver for the production of glucose (gluconeogenesis), fatty acids or ketone bodies. The quantity of amino acids catabolised increases with increased feed intake, particularly when intake exceeds the quantity required for protein synthesis. They are preferentially oxidised by the liver as a source of energy. Urea excretion increases. Catabolism is also increased when the composition of a mixture of amino acids is unbalanced. Certain non-essential amino acids: glutamate, aspartate, alanine, and the branched chain amino acids, leucine, isoleucine, and valine can be rapidly oxidised in most tissues. Branched chain amino acids are primarily oxidised in muscles.

During exercise protein synthesis decreases and catabolism increases in muscles and also in the viscera. Training decreased the catabolism of amino acids during exercise in the endurance horse. Blood concentration of urea, creatinine and uric acid increases during exercise and continues for several hours after work ends. Urea is eliminated in sweat since the speed of renal excretion doesn't increase during exercise.

1.4.2.4 Urea metabolism

The liver transforms the amino groups of all catabolised amino acids (energy production, gluconeogenesis, ketone body formation) as well as the majority of ammonia absorbed from the digestive tract into urea. Urea quantities increase as the amount of protein ingested increases. Urea is excreted immediately by the kidneys in the urine, in the digestive contents by simple diffusion across the intestinal wall and digestive secretions (saliva). Urea in digestive contents is rapidly hydrolysed to free ammonia by the microbes in the large intestine on the same basis as feed or endogenous amino acids. Nitrogen may then be reabsorbed either directly in the form of ammonia, in the form of amino acids resulting from microbial synthesis or as ammonia produced by the degradation of microbial proteins (Figure 1.13).

Two thirds of the urea produced by the liver is excreted into the large intestine, which results in recovery of about half the nitrogen. Under normal conditions the liver captures all the absorbed ammonia, which is added to that produced by the intestinal cell wall itself from amino acids, such as glutamine. The liver transforms it into urea, but it also uses it to synthesise non-essential amino acids (alanine). Certain essential amino acids may also be synthesised if the corresponding carbon skeletons are available. The recycling of endogenous urea is a conserving mechanism, which permits the animal to better retain part of the ingested nitrogen when diets may be nitrogen deficient. It also serves to provide nitrogen to the large intestine microbes that may be deficient in the same situation.

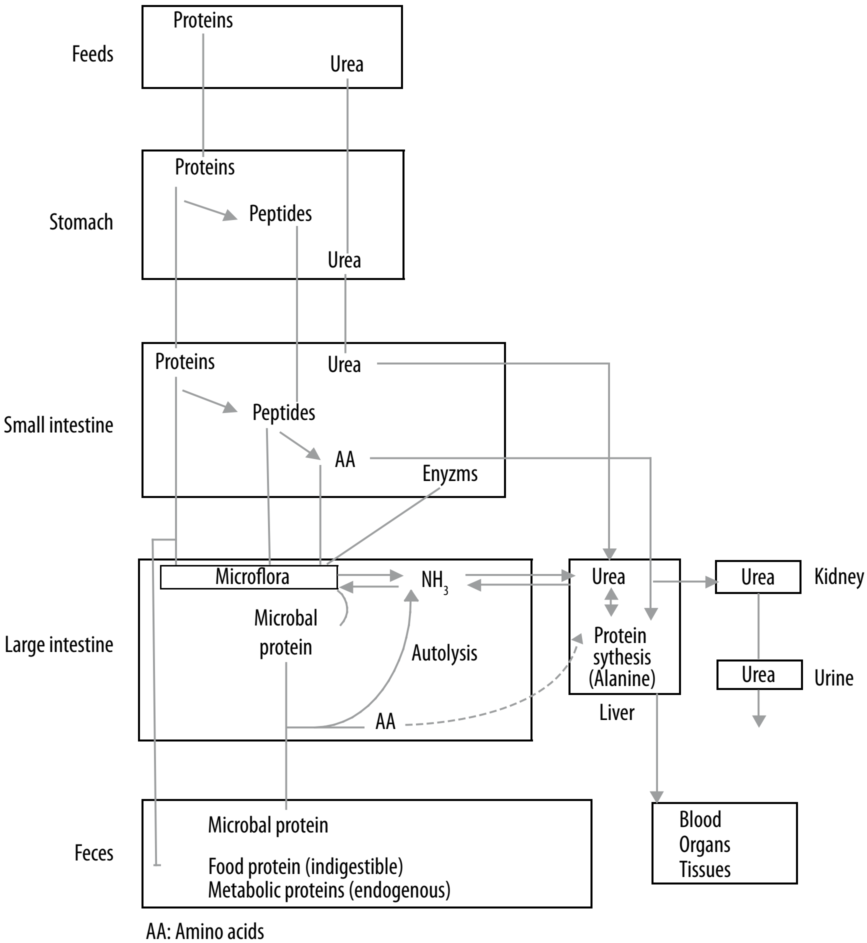

Figure 1.13. Digestion and metabolism of nitrogen containing matter (Robinson and Slade, 1974).

1.4.2.5 Nitrogen losses and requirements

Under the physiological conditions of maintenance the animal body undergoes inevitable losses of nitrogen in urine and faeces, even if it receives a perfectly balanced diet as to the content of protein, energy constituents, minerals, etc. These losses, termed endogenous, are generated by the digestive and metabolic functions of the body.

The loss of endogenous urinary nitrogen is represented by the products (urea, ammonia) of catabolism of a portion of the amino acids, a result of their excess supply after post-prandial absorption and renewal of body proteins. Related to weight, it diminishes with age at the same time that the rate of protein turnover decreases. Losses of endogenous faecal nitrogen are a result of the fact that nitrogen in digestive secretions (enzymes, urea, mucous) and sloughed epithelial cells are not fully recovered. Part of total nitrogen losses is excreted directly in faeces and, greater quantities in the form of microbial proteins. In a given animal it increases with the quantity of dry matter intake and with the dietary content of plant cell wall (crude fibre).

These endogenous losses correspond to minimal values observed when an animal consumes a diet containing little or no protein, but has the right amount of other nutrients. This has never been measured in horses. It was estimated from the relationship between the quantities of nitrogen excreted and the quantities of nitrogen eaten. Endogenous urinary losses were estimated at between 128 and 165 mg per kg of metabolic weight ($BW^{0.75}$). Endogenous faecal losses were estimated at 3 g per kg of dry matter eaten from the results of 145 digestibility trials.

Animal also undergo inevitable loses of nitrogen from the skin: replacement of sloughed cells, cutaneous secretions, continuous growth of appendages (hair, hooves). In the absence of direct measurements, besides being very difficult, in horses it has been estimated at 35 mg/kg $BW^{0.75}$ or twice the value developed for cattle. Sweat losses which contain approximately 1 g nitrogen per litre but are greater if nitrogen intake is excessive. These losses are not yet accurately evaluated but could be significant. It has also been stated that the quantity of nitrogen not excreted in the faeces and urine increases with work and the quantity of feed, and therefore nitrogen, eaten.

The quantities of protein incorporated by the growing horse or in pregnancy, or produced by the lactating mare are stated in the relevant chapters of this book (Chapters 3 and 5). The total costs of maintenance and production represent the daily nitrogen costs or the net daily nitrogen requirement. It must be met by amino acids (as well as ammonia) absorbed from the intestine. This is influenced by urinary losses (urea) and exogenous faecal losses that are added to endogenous losses. These losses are minimal and, in correlation, the efficiency of metabolic utilisation of digestible proteins (or nitrogenous compounds) in the diet is maximal, when the concentration of these proteins in the diet, their essential amino acid composition, energy intake and other nutrients are perfectly balanced to the quantitative and qualitative needs of the animal.

Protein deficiency, or of certain essential amino acids, is visible as general rather than specific disorders. Initially, there will be a loss of appetite, which will lead to energy deficiency. Soon after there would be a loss of weight in adults, reproductive disturbances, a reduction in weight and vitality of foals at birth and reduced growth and development.

1.4.3 Digestive utilisation of nitrogenous compounds

The nitrogenous constituents of feeds are divided into two categories: non-protein constituents and proteins. Non-protein constituents make up 15 to 20% of the nitrogen in green forages. This proportion is greater in stems than in leaves and in legumes than in grasses. Their content is increased in hays and especially in silages (Chapter 12). Proteins in forages are primarily located in chloroplasts and are well supplied with essential amino acids. They represent 75 to 80% of total nitrogen but the proportion is less in silages. The protein in grains and seeds are found in the form of granules in reserve tissues. They do not have as great a content of essential amino acids as forages.

1.4.3.1 Digestibility and absorption in the small intestine

The apparent digestibility of nitrogenous compounds in the small intestine increases with the quantity of nitrogen in the diet as is demonstrated in Figure 1.14, which contains the most reliable results.

The apparent digestibility of crude protein of forages ranges from 15 to 30%, while that of concentrate feeds extends from 50 to 80%. True digestibility when nitrogen of endogenous origin is eliminated, is much higher: 40 to 60% for forages and 60 to 90% for concentrate feeds (Chapter 12). True crude protein digestibility of forages (which overestimates that of protein due to the fact that the digestion of non-protein nitrogen is very high) is considerable lower than that of concentrates. The protein in concentrate feeds are even better digested in the small intestine when they are in fuller and longer

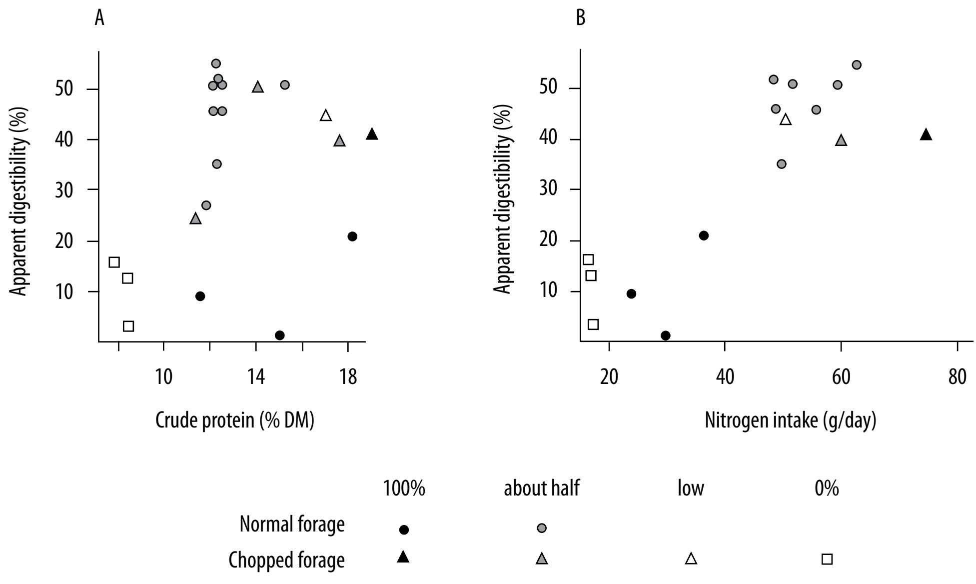

Figure 1.14. Apparent digestibility (%) of crude protein in the small intestine of horses with (A) the crude protein content of the diet (pony, horse, and donkey) and (B) the quantity of crude protein ingested per day (pony). (Results obtained using markers by Reitnour *et al.*, 1969; Hertel *et al.,* 1970; Hintz *et al.*, 1970; Wolter and Gouy, 1976; Klendshoj *et al.*, 1979; Haley *et al.*, 1979; Martin-Rosset *et al.*, 1987; Gibbs *et al.*, 1988).

contact with the digestive enzymes. This contact is facilitated by actions that disrupt the cells walls especially by grinding the feeds during their preparation and during mastication. It is easier with thin walled cells of the tissue reserves of seeds than with chlorophyll tissues of forages where accessibility is restricted by a more or less thick epidermis (grasses) and support tissues and which decreases gradually as the plant matures.

Amino acids from the enzymatic digestion of proteins and the urea potentially found in the diet, are absorbed through the wall of the small intestine to be taken up by the liver and utilised by organs and tissues or excreted in urine (Figure 1.13).

In conclusion, the true digestibility of feed proteins in the small intestine has been established for different categories of feeds through well confirmed results obtained in a series of digestion studies using fistulated horses and the use of makers and/or mobile bags particularly at INRA (Chapter 12). The work was initially designed to determine the protein value of feeds.

1.4.3.2 Digestion and absorption in the large intestine

The apparent crude protein digestibility of feeds whole or in various stages of degradation as they arrive from the small intestine as well as endogenous constituents which arrive with them or are secreted by the digestive tract wall vary from 70 to 80%. True digestibility is much higher at 80 to 95% depending on the feeds.

The microbial population derives amino acids, peptides and ammonia from this digestive degradation, which are necessary for their own proteins (Figure 1.13). Bacterial bodies are in turn partially degraded while in the gut, especially in the colon, however, a large amount is excreted in faeces. Bacterial bodies represent about 50 to 60% of total nitrogen excreted, while the remainder consists of endogenous nitrogen (3 g/kg faecal DM), ammonia nitrogen (5-8%) and feed nitrogen attached to indigestible cell walls. The terminal products of this metabolism of residual feed proteins and endogenous substances that the horse can absorb from the large intestine are ammonia and a very marginal amount of amino acids derived mainly from the lysis of microbial cells. A large part of the ammonia absorbed enters the entero-hepatic cycle and also helps meet the microflora's own requirement for nitrogen in the situation where residual feed nitrogen available in the large intestine is insufficient. The absorption of amino acids for use in meeting the host animal's needs is very low.

1.4.4 The 'Matières Azotées Digestibles Cheval' (MADC) system

The protein value of feeds depends on:
- The quantity of amino acids absorbed from the small intestine or the dietary protein truly digestible in the small intestine (PDIa) of feed origin to meet the requirements of the host animal.
- The quantity of amino acids of the residual dietary protein origin available in the large intestine following microbial degradation, and then utilised to meet the microflora's own needs in the large intestine. The amino acids utilised in the large intestine for microbial protein synthesis from residual dietary protein is generally identified as PDI microbial or PDIm.

As a result the sum of amino acids absorbed in the small intestine and used by microbial population in large intestine is identified as protein truly digested in the small and large intestine as PDI.

The amount of MAD (digestible protein) is the first measurable criterion of the quantity of absorbed amino acids provided by the feed. It is an inexact criterion, however, as it does not take into account the amino acids and ammonia absorbed in the terminal products. The differences in digestion of forages and grains or seeds is partly reflected in the value PDI or MADC = PDIa + PDIm.

At equal CP contents the DP content of forages is clearly less than that of concentrate feeds because more of the microbial protein, endogenous constituents, and feed proteins that have escaped digestion are excreted in the faeces. These differences account for some of the differences in the calculated PDI values (Table 1.10). However, it is true that 100 g of forage DP provides less PDI than 100 g of DP from grains and seeds (Figure 1.15).

Account was taken of forage/concentrate differences in reducing (correcting) the CP content of forages. For this we used both the principle developed in 1984 (Table 1.10 and Figure 1.13) and the true digestibility measured experimentally in the small intestine and the utilisation hypothesis of residual feed nitrogen in the form of microbial protein in the large intestine. However, concentrate feeds are also quite different in DP content (the cell walls are more or less digestible) if, for example, cereals and their by-products are compared. The proteins are also more or less accessible to digestive enzymes. This central aspect is taken into account even for concentrate feeds on the same principle

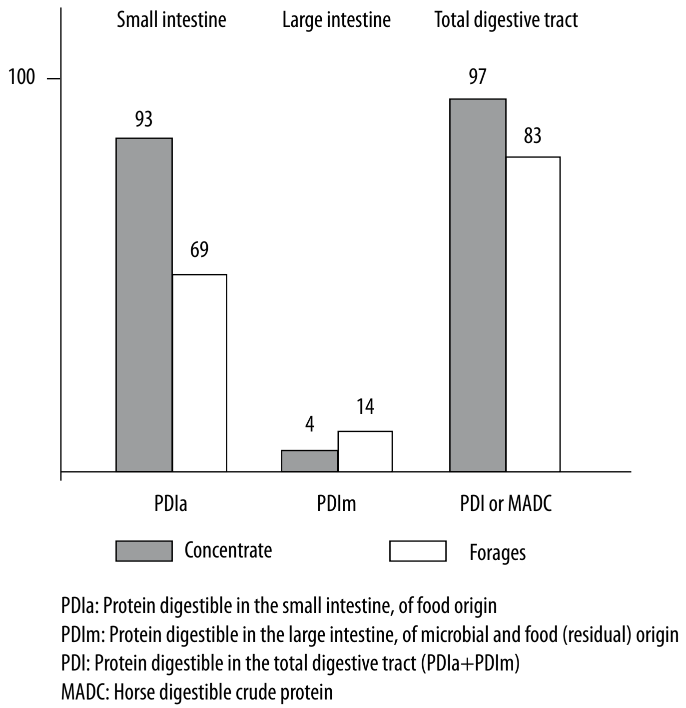

Figure 1.15. Comparative evaluation of protein value of forage and concentrate feeds expressed as MADC for 100 g of digestible proteinDP.

Table 1.10. Principals of evaluation of absorbed amino acid quantities expressed in MADC or PDI, protein digestible in the small intestine (PDIa) or the large intestine (PDIm) of the gastrointestinal tract of the horse: comparison of forages and concentrates (values in g/kg of DM).

	Crude protein		Small intestine			Large intestine				Intestine total	
	Total (g)	NPN (g)	Entry[1] (g)	True dig[2]	PDIa[3] (g)	Entry[1] (g)	True dig[2]	PDIm (%)[4]	PDIm[5] (g)	PDI or MADC[6] (g)	DP[7] (g)
Concentrate feed (CF 8%)	180	9	171	0.85	145	26	0.90	10	2	147	148
								30	7	152	
				0.75	128	43		10	4	132	
								30	12	140	
Early grass and pasture	180	18	162	0.70	113	49	0.80	10	4	117	128
								30	12	125	
				0.60	97	65		10	5	102	
								30	16	113	
Barley-maize mix	110	5	105	0.85	89	16	0.90	10	1	90	90
								30	4	93	
				0.75	79	26		10	2	81	
								30	7	86	
Grass hay (heading)	110	11	99	0.50	50	49	0.75	10	4	54	65
								30	11	61	
				0.40	40	59		10	4	44	
								30	13	53	
Grass silage (heading)	110	28	82	0.50	41	41	0.75	10	3	44	65
								30	9	50	
				0.40	33	49		10	4	37	
								30	11	44	

[1] Data are grams of nitrogenous feed material.

[2] True dig = true digestibility.

[3] PDIa = protein of feeds truly digestible in the small intestine.

[4] Percentage of proteins of feed origin that are degraded and synthesised in microbial protein and/or partially absorbed in the form of ammonia according to the situation in the large intestine.

[5] Amount of PDIm = the amino nitrogen of dietary protein origin utilised in the large intestine for microbial protein synthesis.

[6] PDI = the sum of amino acids absorbed in the small intestine and used by microbial population in large intestine.

[7] DP = digestible protein.

as for forages (Table 1.10 and Chapter 12), but using true digestibilities, measured experimentally by INRA with concentrate feeds.

The evaluation of K factors implemented to estimate MADC value of feedstuffs is based on two sets of digestion trials carried out with forages then concentrates (Martin-Rosset *et al.*, 2012a,b, unpublished data). *In vivo* digestibility coefficients of nitrogen in the total gastrointestinal tract using total faeces collection (TFC) were measured with five adult horses of light breeds (500 kg BW). Then *in sacco* digestion coefficients of N in small and large intestine using mobile nylon bag technique (MNBT) were determined in four caecum fistulated adult horses (500 kg BW). Bags were filled with either 200 mg or 400 mg materials for forages or concentrates, respectively, according to two preliminary experiments (Macheboeuf *et al.*, 1995, 1996). The digestion coefficients determined with MNBT were corrected for mean retention time of bags, particles losses and N contaminations when requested (Macheboeuf *et al.*, 1996; Martin-Rosset *et al.*, 2012a,b). So far N digestion coefficients were so called N disappearance. The total gastrointestinal tract N true digestibility measured *in vivo* and N disappearance determined *in sacco* were estimated both assuming that only dietary N reaching the faeces was N-NDF. N true digestibility or N disappearance was calculated according to the formula proposed by Glade (1984):

$$\text{True N digestibility or disappearance} = \frac{\text{N intake} - \text{residual N-NDF}}{\text{N intake} \times 100}$$

In the preceacal part, MNBT was not directly calibrated with the reference method (ileal flow rate measurement). However, we checked that the MRT of each bag was consistent with physiological measurement using markers as a reference, and that the number of bags collected in the caecum was representative of the total number of bags passing throughout the small intestine. Postileal disappearance rate was measured with bags filled with preceacal residue collected previously and then reintroduced in new bags into the large intestine. The sum of preceacal and postileal disappearance rates was checked to be approximately equal to the total disappearance rate in the digestive tract. In addition, residual dietary N feed digested in the large intestine was considered mainly to be dedicated to microbial protein synthesis after degradation of residual N feed and/or more or less from ammonia supplied by urea cycle (Santos *et al.*, 2012), whereas amino acids absorption is marginal (Martin-Rosset and Tisserand, 2004; Santos *et al.*, 2011). Hence, the true N disappearance determined in the total tract was promoted to be the K factor for correcting digestible crude protein, routinely determined *in vivo* for hays using the TFC method to set up INRA 2012 feed tables. This determination includes in the evaluation of MADC (or PDI: Table 1.10) values, both the high proportion of nitrogen absorbed as amino acids in the small intestine (PDIa: Table 1.10) to meet N requirements of animal host and the low proportion of residual feed N used in the large intestine (PDIm: Table 1.10) to cover N requirements microbial population and/or to contribute, via urea cycle, to microbial synthesis according to conditions in the large intestine (Santos *et al.*, 2011).

For example, the digestibility and digestion of 21 hays (grasses, grassland and legumes) with a wide range of N content were determined. N true digestibility and digestion coefficients in total tract using TFC and MNBT were 85.5 and 86.2%, respectively (Table 1.11). N true disappearance coefficients in the small and large intestine averaged 81.7 and 60.4%, respectively, but within a wide range. As a result the proportion of total digestible N intake truly digested in the fore and hindgut averaged 75.6 and 23.0%, respectively (Table 1.11). The true digestion coefficient determined in the total tract (85%) was promoted to be the K factor (0.85) for correcting digestible crude protein, routinely determined *in vivo* for hays using the TFC method to set up INRA feed tables (Chapter 12, Table 12.17).

Hence, the true digestion coefficients evaluated in the total tract for each group of forages for correcting digestible crude protein, routinely determined *in vivo* using the TFC method to set up

Table 1.11. Total, precaecal and postileal digestion of nitrogen of 21 hays (from Martin-Rosset *et al.*, 2012a).

	Average	Min	Max	SE
Chemical composition of forages[1]				
N (g/kg DM)	18.8	7.6	30.7	6.5
N – NDF (% N)	50.4	24.6	62.3	10.8
Digestion in total gastrointestinal tract (%)[2]				
N digestion				
in sacco: disappearance	74.4	60.5	90.2	7.9
in vivo: digestibility	58.5	42.0	74.5	8.6
N true digestion				
in sacco: disappearance	86.2	71.1	93.7	5.2
in vivo: digestibility	85.5	69.2	93.2	4.1
Precaecal disappearance: *in sacco*[1]				
N intake: % apparent	65.2	58.3	81.5	6.8
% true	81.7	73.7	95.1	4.3
% digestible N intake[3]	87.6	70.3	103.2	9.1
% truly digestible N intake[3]	75.6	73.9	90.0	4.3
Postileal disappearance: *in sacco*[1]				
N residual[4] (%)	60.4	23.0	77.8	13.2
% digestible N intake[3]	17.3	7.2	25.4	5.2
% truly digestible N intake[3]	23.0	9.2	33.9	6.9

[1] N: nitrogen; NDF: neutral detergent fibre.
[2] *In sacco*: mobile nylon bag technique; *in vivo*: total faeces collection.
[3] Relative digestion.
[4] N residual: residual feed N reaching large intestine.

INRA 2012 feed tables, were assessed to be the K factor as it includes true PDIa and PDim fraction of N dedicated to meet requirement of animal host and mainly microbial ecosystem of hindgut respectively.

K factors assigned to concentrates in the MADC system (Chapter 12: Table 12.17) were estimated by INRA too from digestion trials over a large range of feeds using again caecum fistulated horses (Table 1.12). Digestion coefficients were determined using the same methodology previously described. True N disappearance determined in the total tract averaged: 90% for cereals and their by-products; 92% for oil meals; 95% for legumes seeds; 71% for dehydrated beet pulp; 81% for dehydrated lucerne and 61% for soybean hulls (Table 1.12). N true disappearance in the small intestine (so called PDIa) was very high within a large range: 83% for cereals and their by-products; 87% for oil meals; 72% for legumes seeds and dehydrated lucerne, but 45 to 50% for dehydrated beet pulp and soybean hulls. The proportion of truly digestible N intake digested in the foregut averaged 86%, but within a very large range (72.0 to 99.8%). True N disappearance in the large intestine (so called PDIm) are still high, but within a wider range between group of concentrates or even within the same group. N true disappearance in the hindgut for rapeseed and sunflower meals; peas seeds, dehydrated beet pulp or

Table 1.12. Total preceaecal and postilleal digestion of nitrogen (N) of 16 concentrates (Martin-Rosset *et al.*, 2012b, unpublished data).

Feedstuffs[1]	Cereals				Cereal by-products				Meals					Others		
	Ground oat	Ground maize	Flaked maize[2]	Groundbarley	Wheat meal	Corn meal	Peas[3]	Peas[4]	Groundnut	Rapeseed	Cotton	Soya	Sunflower	Beet pulp[5]	Lucerne[5]	Soybean hulls
Chemical composition (g/kg DM)[1]																
N	16.4	15.4	14.6	20.2	26.5	16.3	37.5	36.5	75.1	57.3	48.7	79.0	43.0	12.7	26.1	17.8
NDF	344	170	105	277	339	3,460	104	139	290	317	531	128	470	511	445	666
ADF	158	38	28	87	103	167	42	69	154	188	336	63	347	259	341	509
Digestion in total tract *in sacco*																
N true disappearance (%)	94.0	79.3	88.5	96.9	93.8	86.5	95.1	95.3	95.6	89.2	85.7	97.2	94.0	71.4	81.2	60.8
Preceaecal digestion *in sacco*																
N true disappearance (%)	86.0	64.2	88.1	81.4	93.8	83.2	71.3	73.3	93.6	88.5	72.1	91.0	89.8	51.8	70.7	43.8
% truly digestible intake	91.5	81.0	99.0	83.8	99.8	96.0	75.0	77.0	97.9	99.2	84.1	93.6	95.5	72.0	87.0	72.2
Postileal digestion *in sacco*																
N true disappearance (%)	73.1	85.4	-	87.4	-	73.1	94.1	96.2	91.1	94.2	75.3	92.5	93.4	76.7	65.1	69.5
% truly digestible intake	8.5	16.3	-	17.5	-	3.2	20.7	21.2	3.4	2.1	11.2	6.2	6.1	26.9	11.1	27.4

[1] N = nitrogen; NDF = neutral detergent fibre; ADF = acid detergent fibre.

[2] Hydrothermal pressure.

[3] *Cicer arietinum.*

[4] *Pisum sativum.*

[5] Dehydrated.

soybean hulls were higher than in the foregut. In contrast, true N disappearance in large intestine was lower for cotton meal and dehydrated Lucerne. The proportion of truly digestible N intake digested in the hindgut averaged only 11% but within a very large range (0.1 to 27.4%) due to type of concentrates and processing. This residual N is mainly devoted directly or via urea cycle to microbial protein synthesis.

Hence, the true digestion coefficients evaluated in the total tract for each group of concentrates for correcting digestible crude protein, routinely determined *in vivo* using TFC method to set up INRA 2012 feed tables, were assessed to be the K factor as it includes true PDIa and PDim fraction of N dedicated to meet requirement of animal host and mainly microbial ecosystem of hindgut, respectively.

This leads to a correction for the DP value for all feeds by the coefficient, K, specific for each feed category (Table 1.13) which has been determined experimentally by INRA (Chapter 12: Tables 12.17).

This expression of the protein value MADC (MAD corrected or MAD Cheval) allows for the use of current knowledge to best make comparisons among feeds when making substitutions in ration calculations as in the case of the UFC system. In certain circumstances, when requirements are high, it will be necessary to take the feed content of essential amino acids into account.

1.4.5 Requirements of MADC and recommended allowances

Protein requirements and recommended allowances are both expressed in MADC for various functions: maintenance or production. They represent the quantities of MADC that the feeds must provide to meet the horse's losses and expenditures (animal host and microbial ecosystem) and to assure the highest dietary efficiency in preserving health and reproductive capacity. The diet is assumed to be balanced for all other nutrients.

Requirements have been established using three methods: feeding trials (global method); nitrogen balance estimates; measurements of physiological expenditures and the efficiency with which they are converted by the MADC (factorial method) when the protein content and amino acid composition of

Table 1.13. Basic formulas for calculating the MADC value of feeds.

CP
$DP = CP \times d_N$
d_N = apparent digestibility of nitrogen (N)
$MADC = DP \times K$
K = correction coefficient for each feed:
Kf: for different categories of forages[1]
(f1 – f2 – f3 – f4)
Kc: for different categories of concentrate feeds[1]
(c1 – c2 – c3 – c4 – c5 – c6)

[1] The values for K are given in Chapter 12, Table 12.17.

the diet are optimal. The diet is otherwise adequate primarily in energy but also in other constituents regardless of means.

Maintenance requirements are proportional to the size of the animal that is its metabolic weight (Table 1.14). The protein cost of maintenance contributes much less to the behaviour of the animal than does energy expenditure, even though the two are related. Expressing the protein allowance in relation to energy intake takes account of any variations.

Production requirements are added to maintenance requirements:

Total requirements (g MADC/d) = maintenance requirements + production requirements

Production requirements were established by: either product composition and the efficiency of metabolic utilisation of MADC by the factorial method (gestation, lactation), or by relating the quantity of MADC consumed to measure performance in a series of feeding trials (growth, fattening). In the case of work the protein cost is associated with energy use (Table 1.14).

In all situations the allowances have been validated in a series of feeding trials (global method). The allowances correspond to the requirements of the animals.

Table 1.14. Efficiency of metabolic utilisation of digestible protein in horses (MADC) and requirements for various types of production.

Maintenance	
Requirements	
g MADC/d/kg $BW^{0.75}$	2.8
g MADC/UFC	60-70
Gestation	
Efficiency (%)	55
Requirements (g MADC/d/100 kg BW)	13-47
Lactation	
Protein content (g/kg)	20-35
Efficiency (%)	55
Requirements (g MADC/kg milk)	22-44
Growth	
Protein content (g/kg EBW)[1]	180-220
Requirements (g MADC/kg BW gain)	440-450
Work	
Requirements (g MADC/UFC)	60-70

[1] EBW = empty bodyweight.

1.4.6 Balancing the diet for amino acids

Horses are not capable of synthesising, or synthesising at a sufficiently rapid rate, the nine EAA: leucine, iosleucine, valine, methionine, phenylalanine, threonine, tryptophan, and histidine (tyrosine and cystine are semi-essential). The sum of the EAA represents 46 to 55% of muscle proteins, about 37% of total proteins in the body and a little more than half of those in mare's milk.

EAA requirements are essentially met by the digestion of feed proteins in the small intestine. The horse is, therefore, dependent upon the quality of these proteins. Cereals are much less well balanced for EAA than are forages. The horse absorbs relatively small quantities of free amino acids released by autolysis of microbial proteins, which are a good source of EAA, sulphur containing amino acids being the most limiting. This explains why the adult, non-working horse at maintenance is not sensitive to the quality of feed proteins. Besides the horse can make use of non-protein nitrogen sources (urea).

However, the horse in production is much more sensitive since its requirements are greater. Lactating mares must have their requirements for protein better balanced than at maintenance since milk is rich in EAA. The young horse responds to protein quality with higher growth rates throughout its first year. The growth dependent on protein quality decreases as the animal ages, certainly as the capacity for growth decreases and it is fed a diet proportionally higher in forage. In working horses the need for branched chain amino acids may be anticipated when undergoing very intense work. Only the requirement for lysine has currently been determined and is the subject of recommendations.

1.4.7 Comparison with the other (nitrogen) systems

The MADC system has been successfully used in France since the eighties. It was conceived as an additive and simple system for use in practice, making this new concept on protein feeding easily understandable and available to the principal users. Diet formulation and feed evaluation were improved in comparison to the DCP system. It proved to be reliable in respect to its overall coherence since the main steps of its framework were built up interdependently. The estimates of animal protein requirements arose from an evaluation of true N disappearance both in the small and large intestine. As a result, the estimates of animal host and microbial population requirements were directly dependant on the values proposed for feeds. The MADC system is now based on new digestion trials carried out with fistulated horses to evaluate the disappearance coefficients of N over a large range of feedstuffs (forages and concentrates) both in the foregut and hindgut (Martin-Rosset *et al.*, 2012a,b, displayed for forages in Table 1.11 and for concentrates in Table 1.12).

The MADC system copes with most feeding situations encountered in France with well documented tables for a wide range of feedstuffs as well as for equine requirements except for the athlete where some refinement remains to be carried out. The MADC feed values can be estimated very easily by routine laboratories as criteria, analytical methods and tools (equations) are proposed for the main categories of feedstuffs used to feed horses. Feed tables provide the means to easily compare the value of feeds and to calculate or formulate least cost rations and commercial compound feeds.

The recent revision of the system has shown that the conceptual framework and the expression of MADC values in feed tables were flexible enough to introduce further information. Further development of the MADC system is now focused on the estimation of N requirements of the hindgut microbial population (PDIm) more or less in respect of coupling or uncoupling of energy and protein availability (Santos *et al.*, 2011). Under *in vitro* conditions it has been recently shown that the caecal microbial population does use urea N less efficiently than casein in terms of microbial growth, but produces more VFA and ammonia when liberal amount of energy is supplied and N is more or less the limiting nutrient (Santos *et al.*, 2012). But microbial growth would be higher from urea than from casein, whereas available energy is more limiting (Santos *et al.*, 2013) because the microbial cells likely use endogenous materials as an energy source in equines as in ruminants (Russel and Cook, 1995). Hence it will be relevant to determine the protein quantity synthesised by the microbial population (PDIm) using N feed residue and/or urea through the ammonia-urea entero-hepatic cycle to refine the system. A rough estimation has already been attempted by Slade *et al.* (1973). This estimation should be extended by determining fermentable organic matter, which would be more or less required for optimising the process according to degradability of N dietary residue and available ammonia (Martin-Rosset and Tisserand, 2004). Former studies on microbial growth, enzyme activity and metabolism, on ammonia production, absorption and use for supplying N requirements of microbial population would promote a model to refine the evaluation of PDIm which is indirectly, but approximately evaluated by N disappearance determination in the hindgut in the MADC system (Martin-Rosset and Tisserand, 2004). The ultimate improvement of N feed evaluation system will be the estimation of amino acids needed to meet animal host requirements and N requirements of microbial population provided that protein and/or urea can be used by the microbial population.

The similarities in the conceptual framework of the other systems, as well as the differences in the values for the parameters involved should be stressed. NRC proposed to evaluate N value of feeds using CP content of feedstuffs, because there are not enough digestibility data in horses. Indigestible total N in faeces is estimated to range between 35-50 g/kg DM at maintenance (Martin-Rosset *et al.*, 1984, 1987; Slade *et al.*, 1971). Microbial protein and soluble N fraction account for 57 and 8% of total N in faeces, respectively (Meyer *et al.*, 1985; Nicoletti *et al.*, 1980); endogenous N and indigestible N (ADIN) for 22 and 9%, respectively (Meyer, 1983a,b; Olsman *et al.*, 2003; Pagan, 1998). There is some evidence that total N of feeds and ammonia are not entirely digested and/or recycled respectively for further microbial protein synthesis in the digestive tract. Hence the CP system overestimates true nitrogen value of feedstuffs.

The new system proposed in Germany (Zeyner *et al.*, 2010) is based on the estimation of small intestinal digestible CP and amino acids content of feedstuffs (SidCP) in respect of the proportion of insoluble N, so called NDICP (neutral detergent insoluble crude protein) and the corresponding soluble CP, so called NDSCP (neutral detergent soluble crude protein) to discriminate between cell wall and cell content protein. It is assumed that amino acid profiles of both protein fractions are similar within a given feed. This system comes closer to the MADC system as SidCP attempts to evaluate PDIa of feedstuffs using the solubility of N, but the MADC system evaluates true disappearance of soluble N of feeds. Furthermore, the SidCP system underestimates true N value of feedstuffs as it definitely bypasses N requirements of the microbial population of the hindgut (PDIm).

The concept of available protein proposed by NRC, where protein availability is estimated by subtracting NPN and ADIN from CP content, is oriented towards the MADC system but bypasses the true N requirements of the microbial population (PDIm). Another disadvantage of the CP and

SidCP systems is that N requirements of horses are entirely assessed by factorial approach, except for growth (NRC) but the model is not very robust, even after revision in 2007. In the INRA system requirements are based on factorial methods extensively validated by numerous feeding trials.

1.5 Mineral nutrition

Essential minerals are divided into two categories:

- Macroelements or major mineral elements: calcium (Ca), phosphorus (P), magnesium (Mg), sodium (Na), potassium (K), chorine (Cl) and sulphur (S) of which the concentration in feeds and diets is expressed in g/kg or percentage (%).
- Microelements or trace elements: iron (Fe), zinc (Zn), manganese (Mn), copper (Cu), cobalt (Co), iodine (I), molybdinum (Mo) and selenium (Se) of which the concentrations are expressed in parts per million (ppm) or mg/kg.

These elements have roles that are structural (e.g. skeleton), functional, physiological (e.g. cellular osmotic pressure) and metabolic (e.g. enzyme activation). They are provided by feeds in very variable quantities (Chapters 9, 12 and 16), which are often insufficient and/or unbalanced. Mineral supplements must often be added to diets. Allowances must also recognise maximum tolerance limits.

1.5.1 Major mineral elements

1.5.1.1 Role and absorption

Calcium and phosphorus

99% of calcium and 80% of phosphorus in the body are found in the skeleton and teeth. They combine to form the bone mineral substance, hydroxyapatite. Calcium and phosphorus content of bone are approximately 35 and 15%, respectively. Calcium also has fundamental and varied functions in the animal apart from bone structure: membrane permeability, muscle contraction, neuromuscular excitability, blood coagulation, activation of numerous enzymes, while phosphorus is required in energy transfer of adenosine phosphate (ADP) to adenosine triphosphate (ATP) and the synthesis of phospholipids, phosphoproteins and nucleotides (Table 1.15). The role of calcium is so important that it is essentially absorbed in the proximal small intestine. Phosphorus absorption takes place both in the small intestine and hind gut in amounts that vary with the phosphorus content of the ration and nature of the diet. Rations that are very high in phosphorus can have a negative effect on calcium absorption. Similarly phytates and oxalates have a negative effect on calcium absorption as they form complexes with calcium, which make it unavailable.

Calcium is absorbed by a passive (or facilitated) diffusion process and by active transport, but the relative importance of each is not known. Calcium and phosphorus absorption diminishes somewhat with age and also varies with physiological function (Table 1.16).

In general the average ratio of Ca/P of 1.5 is considered correct for horses. Overall the recommendations are to not exceed lower or higher limits than 1 and 3 respectively, which in reality allow for wide variation. An imbalance of calcium and phosphorus associated with inadequate dietary intake (either

Table 1.15. Roles of the principal minerals and trace elements.

Mineral	Roles	Interactions
Magnesium	energy metabolism	phosphorus excess reduces absorption of magnesium
	muscle contraction	
	enzymatic cofactor	calcium antagonist
	DNA and protein stabilisation	
	skeletal integrity	
Potassium	nerve influx	Sodium excess reduces absorption of potassium
	muscle contraction	
	control of osmotic pressure	
Sodium	nerve influx	interaction with potassium
	muscle contraction	
	control of osmotic pressure	
Cobalt	vitamin B12 cofactor	interactions with iron, zinc, manganese and iodine
Copper	collagen synthesis (skeleton formation)	antagonistic to zinc, calcium and iron absorption (secondary deficiency)
	enzyme cofactor iron metabolism	
	protein synthesis	
	nerve impulse conduction	
	superoxide dismutase (SOD) cofactor	
Iron	haemoglobin constituent	interaction with copper, manganese, zinc, cadmium and cobalt
	oxygen transport	
Iodine	synthesis of thyroid hormones	interaction with copper, phosphorus, cobalt, molybdenum, calcium and fluorine
Manganese	enzyme cofactor (protein and carbohydrate metabolism) epiphyseal cartilage formation and bone matrix chondroitin sulphate synthesis	interactions with calcium, copper, phosphorus, iron, cobalt, molybdenum, sodium and magnesium
Selenium	anti-oxidant	interactions with copper and zinc
	vitamin E cofactor	
Zinc	enzymatic cofactor (protein and carbohydrate metabolism)	antagonistic to calcium, copper, molybdenum, sodium, phosphorus, potassium, iron, cobalt, chrome and selenium
	SOD cofactor	

insufficient or excessive) can be the source of bone problems, which may compromise the growth of the foal (Chapter 2).

Magnesium

Magnesium only represents 0.05% of the body mass. It is primarily present in the skeleton (60%) and in muscles (30%). Magnesium plays a role in muscle contraction and in enzyme activation (Table 1.15). Essentially all absorption occurs in the small intestine. Magnesium absorption is good but may be reduced if calcium is in excess. Absorption is not significantly influenced by age or physiological function (Table 1.15).

Table 1.16. True average digestibility's of the major minerals (%).

Mineral	Maintenance	Work	Gestation	Lactation	Growth
Calcium	50	50	50	50	50
Phosphorus	35	35	35	35	45
Magnesium	40	40	40	45	-
Sodium	90	90	90	90	90
Potassium	80	50	80	50	50
Chlorine	100	100	100	100	-

Potassium

The total body contains about 28,000 mEq of potassium located principally in muscles (75%), with only 5% in the skeleton, blood and digestive contents and approximately 10% in other tissues. Potassium is an intracellular cation, which is intimately involved in acid-base balance and osmotic pressure regulation. It also has an important role in muscle activity (Table 1.15). Potassium absorption is high, particularly at maintenance and in gestation (Table 1.16). Increased intake results in increased apparent digestibility.

Sodium

The skeleton is rich in sodium with 51% of body reserves, while muscles and blood contain 11% and skin 9%. Digestive contents are a significant reserve at 12%. The total amounts to about 14,000 mmol in a 500 kg horse. An important influx of sodium (200 to 400 g/l in a 500 kg horse) from the terminal part of the small intestine comes from digestive juices (particularly pancreatic) and products of digestion. 95% of the sodium is reabsorbed from the hindgut. Sodium absorption is very high (Table 1.16). Renal and faecal excretion is proportional to the amount ingested. Sodium has important roles in muscle contraction and control of osmotic pressure (Table 1.15).

Chlorine

The chloride ion is an extracellular anion involved in acid-base balance and osmotic regulation. It has an important role in the formation of hydrochloric acid of the gastric juice, which is fundamental to gastric digestion. Chloride absorption is very high (Table 1.16). In the diet it is generally associated with sodium. The proportion absorbed does not change as the intake of sodium chloride increases.

Sulphur

No sulphur deficit has been reported in horse diets to date. Although it is a major constituent of all proteins (sulphur amino acids: cysteine and methionine) and of enzymes, 85 to 90% of plant sulphur in the diet is in organic form: amino acids and proteins.

1.5.1.2 Principal pathways of mineral metabolism and their control

There has not been sufficient measurement of the intakes and excretion of mineral quantities to determine their utilisation by horses. In the case of calcium, however, as is shown in Figure 1.16, only the amount actually absorbed through digestive processes is used in the building of bones, mineralisation of the foetus, milk secretion and the digestive secretions. A portion of the absorbed minerals is excreted in urine or in sweat. Bone retention of an element is the difference between accretion (quantity of the element fixed in bone: Vo^+) and resorption (quantity of the element released from bone: Vo^-). These two parameters, as well as intestinal absorption and renal excretion, are under effective hormonal regulation.

Intestinal absorption of calcium and phosphorus is stimulated by 1,25-dihydroxyvitamin D3 (1,25-$(OH)_2$D3), the active metabolite of this vitamin, by a process that is independent for each element. Its role for phosphorus is not well understood. It stimulates the synthesis of a binding protein (CaBP) for calcium. 1,25$(OH)_2$D3 also stimulates bone mineralisation (antirachitic action) and resorption. 1,25$(OH)_2$D3 synthesis, which consists of a preferential hydroxylation of the carbon in position 1 of the 25-hydroxyvitamin D3 molecule (hydroxylation takes place in the cells of the renal tubules) is, however, more intense if the plasma concentrations of calcium and/or phosphorus are low. In addition, the liver 25-hydroxylase is active in the new-born foal, in which an injection of 1αOHD3 (derived synthetically, before hydroxylation to 1,25$(OH)_2$D3 in order to be active) produces an increase in plasma concentrations of calcium and phosphorus.

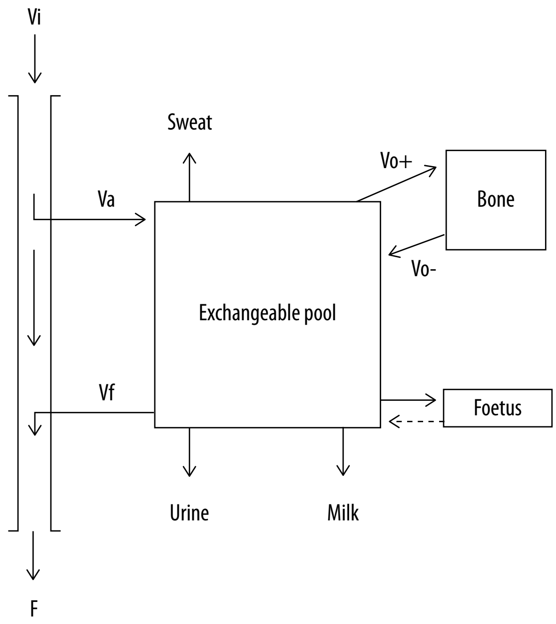

Figure 1.16. Diagram of principal pathways of calcium metabolism in the mare. The symbols identify the quantities of calcium intake (Vi), absorbed from the intestine (Va), excreted as faecal endogenous (Vf), fixed in bone (Vo^+), and released from bone (Vo^-).

Until recently, the principal action of parathyroid hormone was thought to be to stimulate bone catabolism, an action that could produce certain pathological conditions. The problem was known as 'Millers' donkey disease', characterised by an exaggerated curvature of the bones of the zygomatic arches and the ascending branches of the lower jaw, resulting from a nutritional hyperparathyroidism, produced by feeding a diet of bran, which is high in phosphorus and low in calcium. It is the same condition that became known as 'Big Head Disease' among sport horse in the USA. More recently, experiments of prolonged intravenous infusions (lasting several weeks) of very low doses of parathyroid hormone indicate that it is capable of substantially stimulating bone anabolism.

Calcitonin, secreted by the parafollicular thyroid cells, inhibits bone catabolism. The physiological effect is particularly important in preventing demineralisation of the skeleton of the pregnant or lactating mare and to prevent hypercalcemia and/or hyperphosphatemia during periods of rapid absorption of these elements. Calcitonin and parathyroid hormone also act at the level of the kidney: they increase the urinary excretion of phosphates (by lowering tubular reabsorption), thus reducing phosphatemia. Concentrations in horse urine of calcium (20 mg/100 ml) and phosphorus (4 to 18 mg/100 ml depending on feed content) are high. The horse can excrete large quantities of minerals in urine. Foals of one year, weighing 300 kg, receiving diet containing 0.2% calcium, daily excrete 20 to 30 g of this element in 6 to8 litres of urine. Calcium intake and urinary excretion vary in the same direction. The importance of the kidneys in calcium homeostasis in the horse is underlined by the fact that in horses, renal insufficiency or a nephrectomy cause hypocalcemia unlike the hypocalcemia occurring under the same conditions in other mammals, and resulting from a blockage in the synthesis of active metabolites of vitamin D3.

The hormonal regulation of magnesium is not well understood in the horse as in other mammals. It appears that a number of endocrine factors influence this divalent cation in non-specific ways. Plasma concentrations of sodium and potassium are essentially under the control of aldosterone, a steroid secreted by the outermost zone (glomerulosa) of the adrenal cortex. It stimulates renal tubular reabsorption of sodium ions and their intestinal absorption, but it promotes the urinary excretion of potassium.

With all of these regulatory mechanisms the horse normally has a plasma concentration of calcium of 11-12 mg/100 ml, 1-1.5 mg/100 ml of magnesium, 2-8 mg/100 ml of phosphorus, 310 mg/100 ml sodium, and 1.8 mg/100 ml of potassium. If feed intakes are sufficient the physiological state of the horse does not alter these plasma constants. If the latter vary it will be following serious physiological disorders, hence the interest in providing animals diets that provide adequate quantities of minerals.

1.5.1.3 Net requirements and recommended allowances

The horses requirements for major mineral elements was calculated using the factorial method consisting of first evaluating net requirements for maintenance and different production functions then dividing the result by true digestibility (absorption coefficient) for the various elements when it is known. The net requirements correspond to physiological expenditures tied to maintenance, the composition of the weight gain, chemical composition of the conceptus, milk and sweat measured experimentally using the balance method (Figure 1.16).

Requirements were thus calculated and in certain cases a safety factor was added to take in to account possible uncertainties and when results from feeding trials were available to increase precision. These are the recommended allowances provided in Chapters 3 to 8 where they are presented in grams per day. They are also provided in grams per kilo of dry matter intake in Chapter 2, Table 2.1.

The daily maintenance requirement for **calcium** is 0.040 g/kg BW/d as the endogenous loss is 20 mg/kg BW/d and the digestibility of calcium is 50% (0.50) or:

$$\frac{0.020 \text{ g/BW (kg)}}{0.50} = 0.040 \text{ g/kg BW/d}$$

The daily maintenance requirement for **phosphorus** is 0.028 g/kg BW/d as the endogenous loss is 10 mg/kg BW/d and digestibility is 35% (or 0.35) or:

$$\frac{0.010 \text{ g/BW (kg)}}{0.35} = 0.028 \text{ g/kg BW/d}$$

The daily maintenance requirement for **magnesium** is 0.015 g/kg BW/d, as the endogenous loss is 6 mg/kg BW/d and the digestibility of magnesium is 40% (or 0.40) or:

$$\frac{0.006 \text{ g/BW (kg)}}{0.40} = 0.015 \text{ g/kg BW/d}$$

The daily maintenance requirement for **sodium** is 0.020 g/kg BW/d, as the endogenous loss is 18 mg/kg BW/d and the digestibility of sodium is 90% (or 0.90) or:

$$\frac{0.018 \text{ g/BW (kg)}}{0.90} = 0.020 \text{ g/kg BW/d}$$

The daily maintenance requirement for **potassium** is 0.060 g/kg BW/d, as the endogenous loss is 48 mg/kg BW/d and the digestibility of potassium is 80% (or 0.80) or:

$$\frac{0.048 \text{ g/BW (kg)}}{0.80} = 0.060 \text{ g/kg BW/d}$$

The daily maintenance requirement for **chlorine** is 0.050 g/kg BW/d, as the endogenous loss is 50 mg/kg BW/d and the digestibility of chloride is 100% (or 1) or:

$$\frac{0.050 \text{ g/BW (kg)}}{1} = 0.050 \text{ g/kg BW/d}$$

1.5.2 Trace elements

Trace elements are present in very small quantities in living tissues where they play varied but essential catalytic roles: absorption, blood transport, cell storage, elimination or recycling (Table 1.15). Their deficiency results in a blocking or reduction in the efficiency of various metabolic pathways. Their absorption coefficients are largely unknown.

1.5.2.1 Physiologic and metabolic roles

Copper

Copper influences the activity of various enzymes involved in the mobilisation of zinc reserves or iron for the synthesis of haemoglobin and myoglobin. It is involved in superoxide detoxification. It aids in mitochondria preservation.

Cobalt

Cobalt plays a role in vitamin B12 synthesis and in this way influences haematopoiesis and the formation of blood cells in conjunction with copper and zinc.

Iron

33 g of iron are present in the 500 kg horse. It plays a major role in oxygen transport and cellular respiration. This is why 60% is found in haemoglobin and 20% in myoglobin. It is also found in various enzymes.

Manganese

Manganese is involved in carbohydrate and lipid metabolism, as well as in cartilage formation through the synthesis of chondroitin sulphate.

Selenium

Selenium has an essential role in thyroid hormone metabolism as the enzyme involved in triiodothyronine (T_3) is a selenoenzyme located in the thyroid gland. Selenium is also a cofactor in the enzyme, glutathione peroxidase which catalyses the destruction of peroxidases that can harm cellular membranes.

Iodine

This is a trace element that is also a factor in the thyroid gland. Iodine is required for the synthesis of thyroxine (T_4) as well as triiodothyronine (T_3), thyroid hormones that, among other functions, decrease the activity of glutathione peroxydase when selenium intake is insufficient.

Other trace elements

There is insufficient information to date on chromium, fluorine and silica to provide rational information.

1.5.2.2 Requirements and recommended allowances

Requirements of horses are not well known. Most of the requirements are estimated from diets studied in a series of feeding trials and are therefore expressed in mg per kilo of dietary dry matter: these are crude estimates. They are stated in the form of daily recommended intakes (mg/d) for each category of horse (Tables of Chapters 3 to 8) or in terms of concentration (mg/kg DM) in the daily ration (Chapter 2, Table 2.1) as they incorporate the true digestibility of the trace elements. The recommended intakes proposed in Chapters 3 and 8 are the mineral concentrations multiplied by dry matter intake for each physiological situation.

The daily maintenance requirement of trace elements are expressed per kg of dry matter intake: copper (10 mg), zinc (50 mg), cobalt (0.2 mg), selenium (0.2 mg), manganese (40 mg), iron (80 mg) and iodine (0.2 mg).

1.6 Vitamin nutrition

Vitamins are organic compounds essential in higher animals as they are not synthesised in the body, or are not synthesised in sufficient quantities. As a consequence, vitamins must be provided externally, generally in the feed. However, all known vitamins are not essential for the horse as some can be supplied in sufficient quantities through endogenous synthesis. The relativity of vitamin requirements will be discussed. Two main groups of vitamins can be identified as a function of their chemical characteristics: fat soluble vitamins (A, D, E and K) and the water soluble vitamins (B group vitamins and vitamin C) (Table 1.17).

1.6.1 Fat soluble vitamins

1.6.1.1 Vitamin A

β-carotene synthesised by plants is the principal source of vitamin A for mammals. Provided in this form it requires intestinal hydrolysis then absorption. This latter stage is under strict regulation. The enzyme that catalyses hydrolysis is a di-oxygenase (carotenase), which has low activity in horses and which, consequently, requires regular provision of vitamin A in horse diets.

Diet fat content affects vitamin A status. If the diet is low in fats intake of vitamin A is often low and it is poorly absorbed. Horses may then undergo vitamin A deficiency which is manifested by decreased appetite, bone fragility, hyperostosis, skin problems, liver problems, abnormal embryonic development (if the mare is pregnant), muscular degeneration and increased clotting time (Table 1.17).

1.6.1.2 Vitamin D

Vitamin D is a vitamin whose importance is closely associated with calcium. The active metabolic form is dihydrocholecalciferol, hydroxylated in position 25 in the liver and position 1 in the kidney (1,25-dihydrocholecalciferol or 1,25 DHCC) also called calcitrol. It is a steroid hormone. Ergocalciferol (vitamin D2) is present in horse feeds as it is synthesised in plants under the action

Table 1.17. Vitamins: clinical manifestations of deficiency and excess.

Vitamin	Deficiency	Excess
Vitamin A	anorexia, osteo-articular problems, slow growth, erect hair, hyperkeratosis, fatigue, xerophthalmia, reproductive difficulties, foetal resorption, hypertension, LCR, ataxia	slow growth, anorexia, erythemia, bone fragility
Vitamin D	rickets, osteomalacia, osteoporosis	hypercalcemia, calcinosis anorexia, lameness
Vitamin E	sterility (male), dermatoses, immunodeficiencies, anorexia, myopathies	low risk, antagonists vitamin K ?
Vitamin K	low risk, increase in coagulation time, haemorrhages	low risk, anaemia?
Vitamin B1 (thiamine)	anorexia, weight loss, lack of energy, convulsions	drop in blood pressure, irregular breathing, bradycardia
Vitamin B2 (riboflavin)	slow growth, ataxia, vomiting, dermatosis, conjunctivitis, bradycardia, coma	low toxicity
Vitamin B3 (niacin)	anorexia, diarrhoea, slow growth, mouth and throat ulcerations, haemorrhages, nerve troubles	low toxicity, hematemesis, convulsions
Vitamin B6 (pyridoxine)	anorexia, diarrhoea, slow growth, mouth and throat ulcerations, haemorrhages, nerve troubles	low toxicity, anorexia, ataxia
Pantothenic acid	anorexia, lower cholesterolemia, lower lipemia, tachycardia, coma, lower immune response (antibodies)	
Folic acid	anorexia, weight loss, hypochromic anaemia, lengthened coagulation time, leucopenia, glossite, increase in plasma iron, lowered immune response	
Biotine	hyperkeratosis	no observed toxicity
Vitamine B12 (cobalamine)	anaemia, diarrhoea	change in reflexes
Vitamin C	liver synthesis	
Choline	fatty liver (young), increased prothrombin time, atrophy of the thymus, slow growth, anorexia	

of UV rays in sunlight from 7-dehydrocholesterol. Vitamin D2 and vitamin D3 undergo exactly the same transformations to become the same compound: calcitrol.

The signs of vitamin D deficiency are often confused with those of calcium deficiency. In the horse these show as loss of appetite, enlargement of the growth plate cartilages in foals, demineralization of bone resulting in rickets (young) or osteomalacia in adults (Table 1.17). Horses have a very little risk of deficiency except in unusual situations (foals raised inside without access to sunlight and fed diets deficient in vitamin D). In contrast, improper supplementation can lead to a situation of vitamin D excess, which will be more detrimental if vitamin A intake is inadequate. The excess of vitamin D will lead to decreased appetite, growth problems, erect hair coat, anaemia and hyperostosis (Table 1.17).

1.6.1.3 Vitamin E

The term vitamin E encompasses a group of compounds called tocopherols. Vitamin E has an important role as an antioxidant in the body as it prevents the peroxidation of lipids in cell membranes.

The risk of vitamin E deficiency in horses occurs when fresh pasture is unavailable or if poor quality concentrate feeds are consumed. The principal clinical signs are reproductive problems, muscular dystrophy, reduced performance in sport horses, etc. Vitamin E deficiency may also produce erythrocyte membrane fragility leading to shortened cell life span and excessive haemolysis (Table 1.17). Vitamin E is associated with selenium and it is sometimes difficult to distinguish vitamin E deficiency from inadequate selenium intake. However, it appears that selenium deficiency is more common than a lack of vitamin E.

1.6.1.4 Vitamin K

Vitamin K is involved in haemostasis by converting prothrombin to thrombin as well as in the synthesis of osteocalcin, a bone protein involved in the mineralisation process. This vitamin is synthesised in the colon by the endogenous microflora then absorbed. Thus no intake of exogenous vitamin is necessary in horses. Nevertheless, in certain conditions a therapeutic intake may be recommended as necessary. This occurs if there is an intake of antagonistic factors (anticoagulants, especially coumarin compounds), massive destruction of hindgut microflora by antibiotics (rare!) or because of the presence of moulds or aflatoxin in the feeds. In anticoagulant poisoning vitamin K1 is the most active form, while, when intestinal malabsorption occurs, vitamin K3 (menadione) has the most significant effect. The intake of vitamin K has no effect on bleeding in hard working sport horses.

1.6.2 Water soluble vitamins

1.6.2.1 Vitamin C

Horses are able to synthesise ascorbic acid in the liver, and, in light of this, a deficiency of vitamin C is rare. There is no defined requirement for horses.

1.6.2.2 Group B vitamins

The B vitamins are a group of enzymatic cofactors involved in multiple metabolic reactions (Table 1.17). These factors are rarely stored in the body; therefore the requirements are met through the daily food intake or through synthesis by abundant endogenous intestinal microbes in the horse. The risk of deficiency of B vitamins in this species is very low.

Thiamin – vitamin B1

Thiamin in its active form, thiamin pyrophosphate, is mainly involved in the metabolism of alpha-keto acids and the pentose phosphate pathway (oxidative and non-oxidative decarboxylation, transacylation). Deficiency signs are first indicated by dysorexia. Other clinical associated signs are not very specific: slow growth, weight loss and coprophagy. Various neurological symptoms appear in late phases: central nervous system depression, ataxia, paresis, toni-clonic convulsions, marked muscular weakness, cardio-vascular anomalies. Horses can synthesise thiamin in their intestine, however, and a deficiency is not probable.

Riboflavin – vitamin B2

Riboflavin is a major enzymatic precursor involved in oxidation-reduction reactions. Cells use it in the mono or di-nucleotide form (FAD or FMN). Excess is eliminated in urine. In most species riboflavin is synthesised by bacteria in the colon, but the rate of synthesis depends on the animals, the diet and, in particular, carbohydrate intake. Riboflavin deficiency or toxicity has never been described in horses.

Niacin – vitamin B3

Niacin is a cofactor involved in numerous biochemical reactions: oxidation – reduction, post-transcriptional modification of proteins, synthesis of ADP-ribose. All the activities are essential to the cell. In general animals satisfy their requirements for niacin through the intake of nicotinamide and nicotinic acid and partly by the endogenous synthesis from tryptophane. The efficiency of conversion tryptophance-niacin is in the order of 60:1. This conversion also requires vitamins B1, B2 and B6. No requirement for niacin has been determined for horses.

Pantothenic acid – vitamin B5

Pantothenic acid comes in the form of acetyl-coenzyme A or acylproteins in cellular metabolism and it is present in all foods. It is considered to be non-toxic. Allowances have not been documented for the horse.

Pyridoxine – vitamin B6

Vitamin B6 is involved in transamination reactions leading to the synthesis and catabolism of proteins. Vitamin B6 interacts with steroid hormone receptors and modifies their actions. As for other vitamins of this group, the risks of deficiency or toxicity are rare in horses. However, several studies have described deficiencies that are illustrated by various clinical symptoms: changes in the central nervous system, dermatitis, glossitis and anaemia.

Biotin – vitamin B8

Biotin is a cofactor in 4 important carboxylases involved in lipid, protein, carbohydrate and energy metabolism. As for other B vitamins, deficiencies are rare and undocumented.

Folic acid, folates – vitamin B9

This is a group of components also known as vitamin B9. They act a donors or recipients of molecules in intermediary metabolism reactions. Folates consist of a group of components synthesised by plants but also by the micro-organisms of the digestive tract. A chronic folate deficiency is characterised by anaemia very similar to that observed by cobalamine deficiency. As with vitamin B12 a deficiency is exceptional in horses since synthesis by the flora of the digestive tract is an important source.

Cobalamine – vitamin B12

Cobalamine was the most recent vitamins discovered, but deficiency symptoms have been known since the 19th century. It is an important enzymatic cofactor involved in synthesis reactions of methionine and methylmalonyl-coenzyme A (lipid synthesis). Along with other compounds it has a role in DNA metabolism, haemoglobin synthesis and the metabolism of catecholamines. There is storage in the liver and endogenous production by colon microflora, which compensates for irregular intake in feeds.

Vitamin B12 is synthesised in large quantities in the hindgut of horses and deficiency is unusual. The synthesis requires cobalt but in very small quantities (1 μg/kg BW). However, situations can put horses at risk. Examples are foals whose dams are in bad condition and horses in a chronic disease state (haemorrhaging, chronic diarrhoea, etc.). Any deficiency of cobalamine secondary to a digestive tract infection must be treated by parenteral administration (250 μg/kg BW IM per week for 8 weeks). This treatment (antibiotic therapy, pancreatic extract, etc.) is necessary for therapeutic success. It is then necessary to control cobalaminemia by stopping exogenous intake.

Choline

Choline is involved in lipid metabolism, particularly in the liver. A deficiency produces thymus atrophy and liver dysfunction. This will result in lower protein synthesis, which is indicated by a marked hypoalbuminemia and fatty infiltration of the liver (greater synthesis of lipoproteins). The requirement for horses is unknown.

1.6.3 Requirements and recommended allowances

Requirements for horses are not well known, apart from the major vitamins A, D, and E. They are expressed in International Units (IU) for fat soluble vitamins or in mg for water soluble vitamins. The daily recommended allowances are provided for each type of horse (Tables of Chapters 3 to 8) or as concentration (IU or mg/kg DM) (Chapter 2, Table 2.1).

1.6.4 Comparison with other systems (macrominerals, microminerals and vitamins)

Since the last INRA edition, 1990, research carried out on macrominerals has increased substantially whereas studies on microminerals and vitamins are still limited and scarce respectively (see reviews in the following proceedings of several meetings held in the USA: KER, 2000 or in Europe: EWEN, 2005, 2006, 2008, 2010, 2012 or by NRC, 2007). The functions of these nutrients and their nutritional regulation are established for most (Tables 1.14 and 1.16). Signs of deficiency or excess have been also described (Tables 1.15 and 1.17). Relevant publications available to evaluate requirements are only numerous enough for macrominerals (n=111 publications) and to a lesser extent for a limited number of microminerals (n=45 publications) but not for vitamins (n=23 publications). Roughly half of the data extracted from this literature deals with absorption whereas the remaining portion reports data on tissue content of these elements (foetus, milk, bones) including variation in the concentration of these elements in blood or plasma in respect of different factors of variation linked to animal and/or diet. There are very few data about the relationships between intake, excretion and concentration in tissues. Sometimes performance is included. Sufficient evidence was available to permit use of the factorial method to estimate the requirements for macrominerals. We agree with the models proposed by NRC (2007) though we have sometimes introduced into the models digestibility coefficients promoted by INRA (Table 1.15). They recognise the different physiological status and influence of the chemical composition of feedstuffs (Chapter 16). As a result the requirements calculated by INRA are closer in this new edition than in the previous one to those published by NRC (2007). These new INRA requirements are likely more accurate than those published previously (Martin-Rosset, 1990). However, INRA (2012) requirements are not exactly considered as recommendations according to the definition given in this chapter (Sections 1.1.1.1 and 1.1.6.3) because there is still a lack of feeding trials and balance experiments to validate the calculations as was done for energy or protein. Requirements for macrominerals are expressed on a weight basis for maintenance, stallions, pregnant mares, growing horses, exercising horses and, in respect of milk yield, for lactating mare, daily gain for young horse and sometimes with bodyweight variation linked to sweating for exercising horse.

Micromineral and vitamin requirements proposed in this edition remain close to those of INRA (1990) as there is still not enough information to change them and, in addition, to provide recommendations. The requirements are expressed on a kg DM daily intake basis (Chapter 2: Table 2.1) to take account of the tables of feed composition (Chapter 16) and to focus rationing on toxicity risk (Chapter 2: Tables 2.12 and 2.13).

1.7 Major health problems

Health problems may develop when the intakes of minerals and/or trace elements are insufficient, when they are out of balance, or when their intestinal absorption is disturbed and finally when hormonal control of their metabolism is not functioning as required. Intakes of the major vitamins are also of concern in certain situations (Table 1.17).

1.7.1 Osteo-articular pathologies

These pathologies are the most insidious. They result from errors in intake of minerals and/or vitamins (see micronutrients).

1.7.1.1 Osteofibrosis

This is the most severe disease and is commonly related to calcium deficiency usually associated with an excess of phosphorus. It may occur in both young and adult horses. It is a result of secondary hyperparathyroidism which initially produces a demineralisation of normal bone followed by a hypertrophic transformation of fibrous tissue. In certain areas, the bone is the site of a modification called fibrous metaplasia, which is an uncontrolled proliferation of fibrous tissues producing a thickening or local deformation of the bone surface. The bone becomes quite fragile. These lesions occur on the head (a symmetric thickening of facial bones: 'hippopotamus head' found previously in miller's donkeys or, more frequently in the limbs (splints, spavins, hard defects of a general nature, well recognised by riders). When these malformations are located in joints or tendon sheaths they produce severe lameness, which may be permanent or intermittent.

1.7.1.2 Rickets

Rickets results in abnormalities of development and bone growth that produce deformations of the skeleton (hypertrophy of ends of bones) in the young horse. It is a lack of mineralisation of bone following a deficiency of calcium and phosphorus associated with insufficient vitamin D. This problem is relatively rare compared to osteofibrosis.

1.7.1.3 Osteomalacia

It results from the same conditions as rickets, but involves mature bones that are undergoing remodelling and are insufficiently remineralised. It does not cause significant deformations.

1.7.1.4 Osteochondrosis

This is a rapidly developing bone problem in young horses destined to be athletes competing on race courses or high level sporting competitions. According to an epidemiological study, 30% of these horses are affected. It is characterised by an endochondral ossification fault that develops in different ways depending on its appearance site. Currently it is most frequently seen in cartilage as osteochondrosis dissecans, and as subchondral bone cysts.

The disease has a multifactorial nature. It may be genetically controlled as the heritability is, on average h^2=0.30, due to trauma or a vascularization problem of the epiphyseal cartilage. It may also have a nutritional cause. Maximum feed intake with a very high energy concentration because of high grain intake and, therefore high starch intake, representing 40% of the ration and more than 30% of ration dry matter may be determining factors. Unbalanced mineral intakes with an incorrect Ca/P ratio as well as low copper intake can be aggravating factors. Paying attention to proper growth strategies and the recommended, balanced, feed intakes is important (Chapter 5).

1.7.1.5 Osteoporosis

Osteoporosis is characterised by bone deformities associated with failure of the synthesis and structure of bone matrix. It results in fractures are the bone becomes porous due to inadequate mineralisation. Insufficient protein intake is rarely the primary cause. Zinc and copper deficiencies associated with excess calcium are more frequently implicated.

1.7.2 Muscle diseases

1.7.2.1 White muscle disease in foals

The only trace element deficiency of prime importance in horses is that of selenium. It is the cause of white muscle, which is observed very early, within several weeks of birth or in somewhat older animals (yearlings). It develops with the appearance of degenerative zones in skeletal or heart muscle that have a pale colour (giving name to the disease). It can lead to locomotor difficulties or death from cardiac insufficiency. In older horses for slaughter selenium deficiency results in the development of fibrolipomatose lesions which are the main cause of seizures in slaughterhouses.

Selenium deficiency is linked to selenium deficiency in forages, which in turn is related to selenium deficient soils. This may be remedied by selenium intake in a mineral supplement or by injection of selenium compounds into the pregnant or lactating mare. Selenium intake must be carefully monitored as excess intake can lead to severe toxic results. Intake of vitamin E in association with selenium has a beneficial additive effect.

1.7.2.2 Enzootic myopathy in adult horses

This problem has the same cause as the latter. Clinical symptoms are the appearance of red-brown urine under conditions of stress. These may be environmental: cold, transport; its appearance reveals a chronic deficiency of selenium.

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Chapter 2. Diet formulation

William Martin-Rosset, Luc Tavernier, Catherine Trillaud-Geyl and Jacques Cabaret

Diet formulation consists of choosing feeds and calculating the amounts required to be offered to the animals that will provide all the nutrients they require. The diet thus constituted has to cover the expenditures of maintenance and production (milk, growth, work, etc.) and keep the animal in good health.

- To formulate diets knowledge of the following is necessary:
- nutritional requirements of the animals or the recommended dietary intakes of energy, protein, minerals, trace elements and vitamins listed in Chapters 3 to 8;
- conditions influencing use of the feeds, that is ingestibility (e.g. factors linked to feeds characteristics governing intake) or the quantities of feeds that horses will spontaneously consume without risking digestive upsets or health (Chapters 9 and 12);
- the nutritive value of feeds characterised by their energy and protein values, their content of minerals and trace elements presented in Chapters 12 and 16, as well as the appendices;
- feed prices on a kg basis or calculated in comparison with their nutritional values expressed in UFC and per 100 g MADC to permit accurate comparisons.

2.1 Nutritional requirements and recommended nutrient allowances

Recommended nutrient allowances are derived from feeding trials conducted by INRA and IFCE under normal management conditions.

2.1.1 Difference between nutrient requirements and recommended nutrient allowances

Generally the quantity of nutrients provided by the diet or dietary intake, must exactly meet the nutrient requirements of the animals. However, it is not always possible (for physiological reasons) or desirable (for economic reasons) to exactly meet these requirements every day. In practice in most cases, nutrient intake is greater than nutritional requirements, which takes account variation in requirements among individuals placed in the same situation of environmental conditions, or health that are not always optimal. There may also be dietary imbalances due more or less to a poor choice of feeds or slightly incorrect estimations of their nutritional value.

Nutrient intake may, in situations be less than the horse's nutritional requirements: the draft mare during the winter feeding period (end of gestation, early lactation), when feed is expensive, and for the performance horse during a period of intense work when daily quantity of feed consumption may not be adequate to satisfy requirements without health risks (e.g. digestive disorder: colic; metabolic disorders: myoglobinuria). It is assumed that these horses are capable of withstanding a temporary, but significant energy deficit that may be extensive (several months in winter) in the case of the draft mare, or limited and short (several days) in the case of the performance horse. Temporary weight loss, using fatty body reserves accumulated at pasture for the mare or during periods of rest or light training for the performance horse will satisfy energy needs. For these reasons only physiological or

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economic constraints will be considered when discussing recommended daily nutrient allowances in this chapter.

2.1.2 Tables of recommended allowances

Recommended daily dietary allowances are shown in tables designed to permit easy calculation of daily rations. Separate tables are included for light horses, draft horses and ponies. Different formats have been selected for each breed based on bodyweight (adult geldings and mares): light horses: 450 – 500 – 550 – 600 kg; draft breeds: 700 – 800 kg and ponies: 200 – 300 – 400 kg. In each case, mares, stallions, geldings, and growing horses (light, draft or pony) or fattening horses (draft) have been identified. Their various physiological states are also identified: maintenance, gestation or lactation, breeding or sexually quiescent, growing or fattening (draft), resting or at work. The proposed practical rationing has been developed from feeding trials conducted during the winter period, the only such study to date. These tables are contained in special Chapters corresponding to mares (Chapter 3), stallions (Chapter 4), growing horses (Chapter 5), working horses (Chapter 6), and meat horses (Chapter 7). Information for ponies is presented in Chapter 8.

2.1.2.1 Energy, protein, macrominerals

The developed tables provide total daily feed intakes for energy (expressed as UFC), protein (expressed in g of MADC), the major minerals: calcium (Ca), phosphorus (P), magnesium (Mg), potassium (K), sodium (Na), and chloride (Cl) – all expressed in grams, trace elements: copper (Cu), zinc (Zn), cobalt (Co), selenium (Se), iron (Fe), manganese (Mn) and iodine (I) – all in milligrams, and vitamins A, D and E – expressed in International Units (IU). All of the above relate to the following cases:

- horses or ponies at maintenance;
- mares in gestation or lactation (i.e. maintenance + gestation or lactating);
- stallions in or out of breeding season (i.e. maintenance + breeding service + exercise);
- growing horses or ponies (i.e. maintenance + growth);
- horses or ponies at work (i.e. maintenance + work);
- fattening draft horses (i.e. maintenance + fattening).

The recommended feeding allowances published in 1984 in 'Le Cheval' (INRA, 1984) were reworked and published in 'L'alimentation des chevaux' (INRA, 1990), and again in 2012 and provided in this work (INRA, 2012).

Recommended allowances for maintenance

The recommended allowances for maintenance relate to the horse out of any productive activity, in particular not having worked for several weeks in order to distinguish the situation of the competition horse momentarily at rest (lay-up) due to fatigue or health concerns, but still in light maintenance work (Chapter 6).

Example 2.1. Recommended daily allowances for maintenance of a light horse weighing 500 kg (from Chapter 6, Table 6.14).

UFC	MADC	Calcium	Phosphorus	Sodium
4.1	267 g	20 g	14 g	10 g

Example 2.2. Recommended daily allowances for an adult draft horse weighing 700 kg (from Chapter 6, Table 6.18).

UFC	MADC	Calcium	Phosphorus	Sodium
5.1	357 g	28 g	20 g	14 g

Recommended daily allowances for gestating or lactating mares

The recommended allowances for gestating or lactating mares may be greater than, less than, or equal to actual nutritional requirements depending upon breed: draft or light horse or physiological state: month of gestation or lactation (Chapter 3). For ponies allowances are estimated to be requirements because of insufficient information (Chapter 8).

Example 2.3. Recommended daily allowances for a light horse mare of 500 kg in the first month of lactation (from Chapter 3, Table 3.7).

UFC	MADC	Calcium	Phosphorus	Sodium
8.5	956 g	56 g	49 g	13 g

Recommended allowances for stallions

The recommended allowances for stallions are provided for breeding and non-breeding periods, consisting of one hour of light, in hand work daily (Chapter 4).

Example 2.4. Recommended daily allowances for a light horse stallion with a bodyweight of 500 kg in breeding season under average service (from Chapter 4, Table 4.2).

UFC	MADC	Calcium	Phosphorus	Sodium
7.6	547 g	35 g	21 g	19 g

Recommended allowances for young growing horses (draft or light breeds) and ponies or fattening horses (draft breeds only).

The allowances for growing horses are recommendations for a given age. Bodyweights and indicated growth rates correspond to the average attained during a period of growth or fattening (Chapters 5-7). With the growing light horse account is taken of expenditures related to physical activity from 1.5 year or 2.5 years of age appropriate for each breed: racing or competitive sport, respectively.

Example 2.5. Recommended daily allowances for a growing light horse of 8 to 12 months of age (1st winter following weaning) with an expected adult weight of 500 kg, housed in a box stall with a target daily growth rate of 750 g (from Chapter 5, Table 5.8).

UFC	MADC	Calcium	Phosphorus	Sodium
5.1	567 g	37 g	25 g	7 g

Recommended allowances for work

The recommended allowances for work are given for several intensities in Chapter 6 and for durations appropriate to observed current practical situations for leisure, competitive sport, racing and draught.

Example 2.6. Recommended daily allowances for a sport horse weighing 500 kg under average daily work load (2 hours/d) (from Chapter 6, Table 6.14).

UFC	MADC	Calcium	Phosphorus	Sodium
7.8	562 g	35 g	21 g	18 g

To calculate allowances necessary to satisfy particular work conditions, allowances for the workload undertaken must be added to recommended allowances for maintenance (shown in Chatper 6, Tables 6.12 to 6.15). Recommended allowances per hour of work are indicated in Figure 6.11 of Chapter 6 for light horses (leisure, sport and racing) and in Section 6.2.2.3 of Chapter 6. Data for ponies are provided in Chapter 8, Tables 8.1, 8.4 and 8.7 for typical current situations.

Example 2.7. Recommended daily allowances for an adult sport horse weighing 500 kg under a daily work load (2 hours/d) consisting of 1 hour of light work and 1 hour of intense work.

UFC	MADC	Calcium	Phosphorus	Sodium
7.1	497 g	38 g	25 g	28 g

2.1.2.2 Minerals, trace minerals and vitamins

The recommended daily intakes are provided in the tables of Chapters 3 to 8. However, they may also be calculated from the information in Table 2.1 where they are expressed in kg of ration dry matter (Chapter 13, Section on method of calculation).

Table 2.1. Nutrient concentration of diet for horses (per kg dry matter intake displayed in the tables of recommended daily nutrient allowances in Chapters 3 to 8.

	Adults			Mares		Young horses[3]		
	rest and light exercise	work and moderate mating	work and very intense mating	late gestation[1]	early lactation[2]	6-12 months	18-24 months	32-36 months
Energy								
UFC	0.45-0.65	0.50-0.65	0.55-0.75	0.50-0.60	0.55-0.65	0.60-0.95	0.60-0.80	0.50-0.65
Nitrogen								
MADC (g)	30-50	40-50	50-55	35-60	60-65	60-100	35-55	25-35
Lysine (g)	3.0-4.0	4.0-4.5	4.5-5.0	4.5-5.5	5.5-6.0	5.0-10.0	3.5-5.5	3.0-3.5
Minerals (g)								
Ca	2.0-3.0	2.5-3.5	3.5-4.0	3.5-4.5	3.5-4.0	4.0-6.5	3.5-5.0	3.5-4.5
P	1.7-2.2	1.8-2.5	2.4-2.8	2.6-3.8	2.8-3.2	2.8-4.0	2.7-3.5	2.6-2.8
Mg	0.9-1.1	1.0-1.4	1.3-1.8	0.8-0.9	0.7-0.8	0.8-0.9	0.7-0.8	0.7-0.8
Na	1.1-2.0	1.5-2.5	2.3-4.0	1.0-1.5	0.8-1.0	1.0-1.2	0.9-1.1	1.1-1.2
Cl	4.5-5.5	4.5-6.0	6.0-8.0	4.0-5.0	3.0-3.5	3.0-4.0	3.5-4.5	3.5-4.5
K	2.5-4.0	3.0-4.0	3.0-4.5	3.5-4.0	5.0-5.5	2.5-35	3.0-3.5	3.0-3.5
Trace elements (mg)								
Cu	10	10	10	10	10	10	10	10
Zn	50	50	50	50	50	50	50	50
Co	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Se	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Mn	40	40	40	40	40	40	40	40
Fe	50 to 80	80	80	80	80	50	50	50
I	0.2	0.2	0.2	0.2	0,2	0.2	0.2	0.2
Vitamins (UI)								
A	3,250	3,750	3,750	4,200	3,800	3,450	3,500	3,500
D	400	600	600	600	600	600	500	500
E	50	80	80	80	50	80	60	60

[1] Last three months of gestation.

[2] First three months of lactation.

[3] During growth period without training.

2.2 Bodyweight and condition

The daily feed allotment is a function of bodyweight. Body condition is an excellent indicator of the quality of the diet formulation.

2.2.1 Concept of bodyweight

Each animal category is defined by its genetic makeup, its sex and age; bodyweight is the safest and best known measurement of the different categories and the individuals. A very large part of the recommended daily intake relates to bodyweight of horses (from 50 to 90% depending on the type of horse). This is the rational of first considering bodyweight in formulating diets for horses.

In most cases bodyweight of horses is only estimated as one does not usually have access to a scale. The precision of the estimate using the 'eye-balling' technique is low. The estimation accuracy of weight can be improved using one or two simple measurements if the horse is made to stand naturally on a level surface (Figure 2.1). Measurements of heart girth and wither height can be combined in an equation related to the type of adult horse.

Bodyweight (kg) = a × heart girth (HG, expressed in cm) + b × wither height
(WH, expressed in cm) + c

With stocky and compact horses bodyweight primarily depends on heart girth, while in light breed horses, size (reflected by height at withers) improves the estimation of bodyweight.

With growing horses (6 months to 3 years) it is possible to use the National Stud (Haras Nationaux, or nowadays the IFCE) weight tape to obtain a direct reading of bodyweight using a cursor. During growth, heart girth and bodyweight change proportionately. Wither height, on the other hand, increases in a different manner and does not improve the estimation of bodyweight. These relationships have been developed by INRA at the research center of Theix and IFCE at the experimental stations of Chamberet in Limousin and Le Pin in Normandy for categories of horses for which sources of error are the most significant (Martin-Rosset, 1990).

2.2.1.1 Light breeds

Broodmares

Bodyweight (kg) (±25 kg) = 5.2×HG + 2.6×WH – 855

Example 2.8. Bodyweight of an adult saddle horse mare having a heart girth = 192 cm, a wither height = 157 cm.

Bodyweight (kg) = 5.2×192 + 2.6×157 – 855
= 552±25

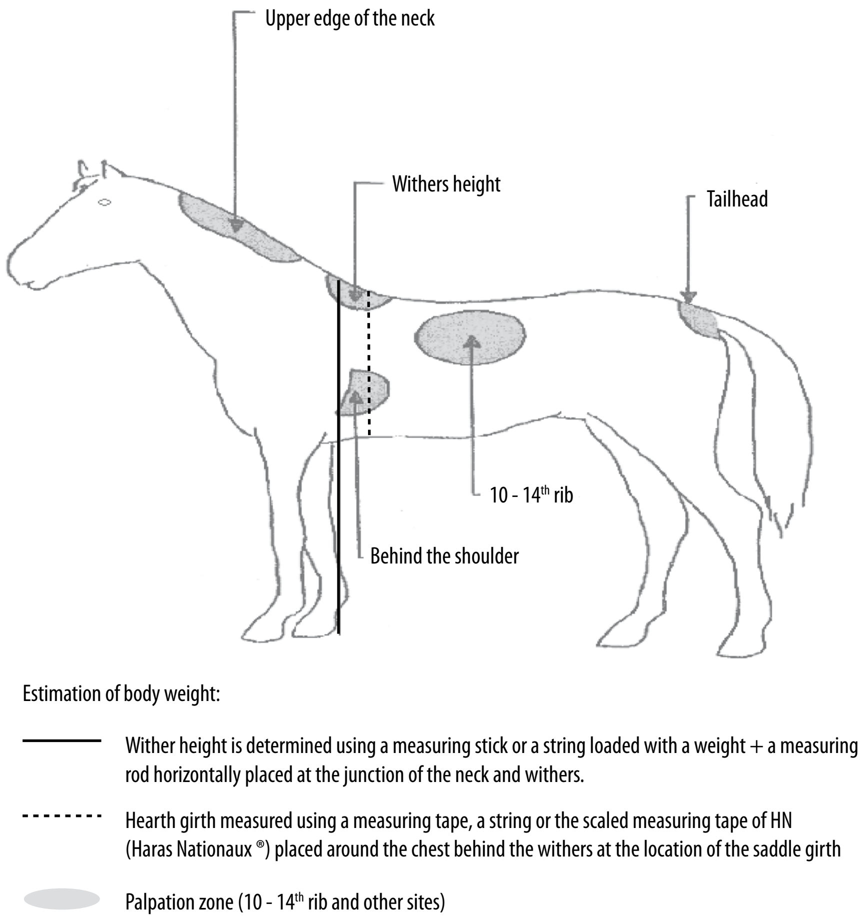

Figure 2.1. Estimation of bodyweight – assessment of body condition (INRA/HN/IE, 1997).

The growing horse (6 months to 4 years)

- Sport horse: bodyweight (kg) (±26 kg) = 4.5×HG – 370

Specific relationships have been established for young racehorses up to 2 years, but knowledge of the exact age (A) plus certain additional measurements is also required (Paragon *et al.*, 2000).

- Thoroughbred: bodyweight (kg) (±15.0 kg) = 0.237×A + 1.472×WH + 1.899×HG – 284.4
- Standardbred: bodyweight (kg) (±15.0 kg) = 0.213×A + 1.783×WH + 2.09×HG – 328.7

Working horses (gelding, stallion, and mare)

Bodyweight (kg) (±26 kg) = 4.3×HG + 3.0×WH – 785

2.2.1.2 Draft breeds (broodmare, stallion, growing or fattening horse)

Bodyweight (kg) (×27 kg) = 7.3×HG – 800

2.2.1.3 Ponies

There is a similar equation derived with adult ponies by researchers at INRA, research center of Tours (G. Duchamp and E. Barrey).

Bodyweight (kg) (±21.3 kg) = 3.56×WH + 3.65×HG – 714.66

2.2.2 Concept of body condition

Body condition is a universal concept that describes the 'fatness' of the animal. Its estimation is important because it is a good indicator of the quality of rationing program as well as body reserves. It is especially important in draft mares as their recommended feed intake is deliberately less than requirements in winter. It is also important in working horses whose feed intakes only meet requirements over an extended period (weeks) due to significant variability in their daily workload.

It is possible to visually evaluate body condition, but this takes considerable experience. It can be evaluated manually by palpating various sites, in particular the area of the saddle (e.g. quarter of saddle) or between the 10^{th} and 14^{th} ribs (Figure 2.1). Condition is rated on a scale of 0 to 5 in quarter or half point increments according to the expertise (Table 2.2). Manual assessment should be repeated in order to evaluate change in condition:

- every 1 to 2 months for horses at work depending on intensity;
- at the start, middle and end of winter for production animals: mares, growing or fattening horses.

Table 2.2. Evaluation scheme to manually determine body condition in horses (INRA/HN/IE, 1997).

Score	Body condition	Observations	
0.0	Emaciated		
1.0	Very thin		
1.5	Thin		
2.0	Moderately thin		
2.5	**Optimum** (depending on the type of horse)	2.5	Mares (draft, pleasure breeds) at the end of gestation or early lactation; competition horse at the end of the competitive season
3.0		3.0	Competition horse during preparation period at the start of competitive season; non-breeding stallion; mare (racing, sport) 2 months before foaling and 1 month after foaling
3.5		3.5	Mares at drying; stallions before breeding season fattening yearlings (draft breeds)
4.0	Fat		
4.5	Very fat		
5.0	Obese		

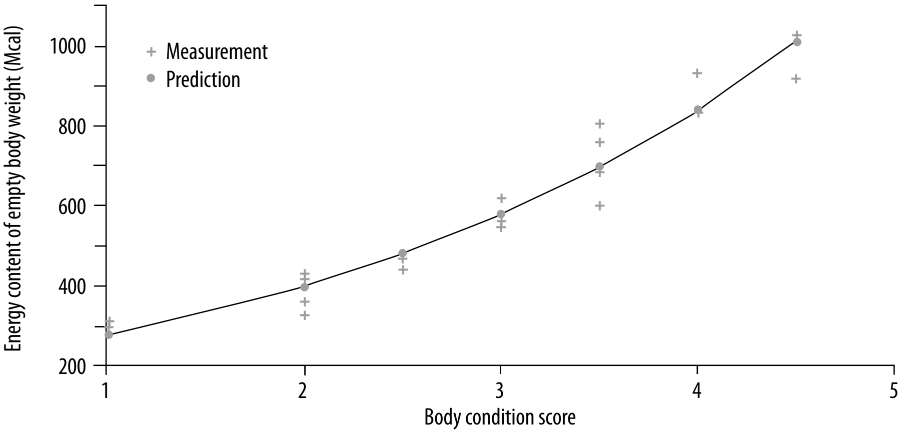

Figure 2.2. Variations in energy content of the empty bodyweight of a 500 kg horse (Martin-Rosset *et al.*, 2008).

In practice, the horse is palpated with the hand at the various sites indicated in Figure 2.1, in particular at the location of the saddle, i.e. between the 10th and 14th ribs. The evaluation consists of (1) the extent of subcutaneous fat tissue deposits when palpating the area, then (2) the thickness of the deposits by pressing on them, and, finally, (3) the consistency by making a circular movement of the hand on the thickest of the deposits. A more complete description of the method may be obtained from a booklet produced by the Livestock Institute (Paris, France; www.idele.fr). This technique was developed using comparative slaughter studies of riding horses having a body condition score ranging from 1 to 4.5. Results of the complete dissection of the horses' bodies established the relationship between body composition and body conditions scores taken before slaughter. These relationships permit the prediction of body composition from body condition scores (Figure 2.2). In practice, some relationships can then be used to adjust the diet depending upon body composition (Table 2.3).

If a body condition score of 3 is considered optimal, the change in gain or loss of empty bodyweight can be determined (Table 2.4).

The energy cost per kilogram of bodyweight is very high (Chapter 1, Table 1.4 and Chapter 5, Figure 5.5). Energy intake cannot be quickly adjusted in hopes of correcting body condition over the short term (several days). Readjusting energy intake must be well planned and introduced over several

Table 2.3. Prediction of the total energy content (TEC) in the empty bodyweight (EBW) of a 500 kg horse from the body condition score (BCS) (Martin-Rosset *et al.*, 2008).

EBW[1] (kg) = 301.527 + 48.181×BCS	R^2 = 0.747
TEC (MCal)/EBW = 190.1 Exp. 0.373×BCS	R^2 = 0.993

[1] EBW (Empty body weight) = bodyweight – weight of digestive tract contents. Average weight of digestive tract contents / liveweight is 12.1% in horses with a liveweight of 400 to 600 kg.

Table 2.4. Relationship between energy content of a kg of bodyweight (BW) and body condition score (BCS) (Martin-Rosset *et al.*, 2008).

BCS	Variation		Change in body energy content	
	BCS	BW (% of BW)	UFC/kg BW	NE (Mcal)/kg BW
4.0	+1.0	11	+2.8	+6.3
3.5	+0.5	5	+2.7	+6.1
3.0	0	0	0	0
2.5	-0.5	6	-2.1	-4.7
2.0	-1.0	11	-1.9	-4.3

weeks depending on observed changes in body condition and making use of the available practical guidelines based on current practices (Table 2.5).

2.3 Quantities of feed ingested

The quantities of feed consumed vary with the characteristics of the feeds and the animals. The feed quantities consumed by the horse must provide the nutrients recommended in the tables to permit expected performance levels to be achieved, to satisfy physiological as well as psychological demands without causing digestive disturbances. The amount of feed that a horse can consume varies initially with the characteristics of the feeds. A riding horse of 500 kg will consume between 60 and 80 kg of

Table 2.5. Energy intake adjustment guide for changes in body condition score at maintenance.

Changes in bodyweight[1]	Changes in BCS[3]	Increase in maintenance requirements[2]		
		30 days	60 days	90 days
1	-0.25	130	115	-
2	-0.25			
3	-0.25			
4	-0.50			
5	-0.50	160	130	115
6	-0.50			
7	-0.75		145	122
8	-0.75			
9	-0.75			
10	-1.0		160	130

[1] As a percent of bodyweight over a bodyweight interval of 400 to 600 kg for a horse starting with a body condition score (BCS) score of 3.

[2] As a percentage of maintenance requirements (=100).

[3] BCS : body condition score

young, fresh forage with high water content (85%), while it can only consume 12 kg of dry meadow hay containing 15% water, if both are offered free choice. This is why it is essential that feed quantities provided to the horse be compared only on a dry matter basis. The dry matter content of feeds is provided in the tables of chemical composition and nutrient content (Chapter 16).

Even on this basis the quantities of feed consumed vary considerably among feeds. A growing light horse, one year of age and weighing 325 kg will consume, on average 7 kg of dry matter of meadow hay while it is only able to consume 5 kg of dry matter of corn silage. Each feed must therefore be characterised by its ingestibility, which is expressed as the quantity of feed that a given animal will spontaneously consume when the feed is offered alone and free choice. Intakes are expressed as kg of dry matter per 100 kg of bodyweight. They are reported under the headings indicated in Chapter 12, Table 12.25 for major categories of forages studied.

Legume hays are consumed in slightly greater quantities than grass hays. Stage of maturity at harvest and number of cuttings do not appear to have an effect on intake of grasses fed as green forage or as hay (Chapter 1, Figure 1.4 and Chapter 12, Figure 12.8). Treatments such as dehydration, wilting or ensiling, which may result in variations in intake are not yet well understood. However, the wrapped, wilted forage is more readily consumed than the same forage fed as hay. Intake of silages is quite variable. It increases with increased dry matter content.

Example 2.9. In fattening yearlings fed diets consisting of 20% concentrate feeds, intake ranges:

- From 0.8 kg DM/100 kg BW for direct cut grass silages harvested with a minimum of 22% dry matter and no preservatives, to 1.8 kg DM/100 kg BW for wilted silages at 36% or more dry matter, to 2.0 kg DM/100 kg BW for wilted silages dried to 50% dry matter;
- From 1.0 to 1.6 kg DM/100 kg BW for corn silages that have been harvested between 25% and 40% dry matter.

Moreover, for the same feed, intake quantities vary with weight, production (milk production, weight gain, work intensity) and stage of gestation or lactation. A range of intakes is shown in the recommended feed intake tables for each type of horse (Chapters 3 to 8). These data do not indicate maximum intakes for horses but the quantities required to meet nutritional requirements. They are in agreement with forage intakes indicated in Chapter 12, Table 12.25 since the ranges shown are the result of feeding trials conducted using these same forages. The upper values of the ranges represent a high forage consumption and economic use of concentrate feeds in mares, working horses and growing horses older than 2 years, for example. The lower values represent a relatively high consumption of concentrate feeds while maintaining a forage intake sufficient to keep the digestive tract functioning properly and to prevent upsets. This diet is typical for horses that need energy dense feeds as is the situation with competition horses, but also need to consume sufficient forage (0.5 to 1.0 kg forage dry matter per 100 kg bodyweight). If such horses do not receive sufficient quality forage they may consume significant amounts of straw bedding (up to 6 kg total as fed per day for a 550 kg horse, the maximum intake to prevent colic or impaction: blockage of the large intestine, preventing food passage).

The quantities of feed provided must be weighed and listed in kg. The quantities of dry forage (hays and straw) fed can be estimated if one knows the density of the bales (Table 2.6). Even better, if a scale is available, a subsample of 10 bales can be weighed at each delivery and an average weight recorded using a portable scale. However, horse owners more and more are using round or rectangular bales weighing 180 to 400 kg. Also the use of a hay net and balance is necessary to provide the daily ration of forage to horses housed in box stalls.

Concentrate feeds should be measured daily using a graduated container, tarred on an accurate balance and properly calibrated. The feed must definitely be measured in kg since 1 litre of barley provides 36% more energy than 1 litre of oats while 1 kg of barley only provides 12% more than 1 kg of oats (Chapter 9, Figure 9.2).

2.4 Water intake

The amount of water drunk varies inversely with the quantity of water supplied in the feed. For diet components that contain a large amount of water (fresh grass, beets, etc.), the water quantity consumed is a supplement to the water in the feed. In contrast, for diets with a low water content (hay, concentrates, etc.) it is wise to provide water to cover the total water requirements of the horses to insure a safety margin taking account of daily and individual variations in intake.

Ideal watering is provided by an automatic waterer, which maintains a constant level without the need of a pressure plate and permits the horse to adjust consumption to requirements. Intakes can vary from 20 to 80 litres per day depending on the type of horse, its physiological state, gestation, lactation, work level, physiological stage (e.g. early or late lactation) and feed characteristics. The amounts of water to provide by bucket are shown in Table 2.7. They are expressed per kg of dry matter or per 100 kg bodyweight. Water must be offered before each meal and, especially, before concentrate feeds are eaten to reduce the possibility of any digestive problems listed in Section 2.5.

Water must be clean and tepid (Table 2.8). The upper concentration limits for potentially toxic elements are provided under their respective names in Table 2.9.

Table 2.6. Variation in weight of dry forage bales related to density.

Forage[1]	Density[2]		
	Low	Average	High
Grasses	12-15	15-18	18-20
Lucerne			
Straw		12-14	15-20

[1] Dry matter content: 82 to 85%.

[2] Bales of 80 cm maximum length.

Table 2.7. Consumption of drinking water by horses: total water intake per kg of dry matter eaten and per 100 kg bodyweight at an ambient temperature of 15 °C.

Diet characteristics	Physiological state	kg water/kg DM eaten	kg water/day and per 100 kg bodyweight
mixed diet (forage + concentrate)[1]	Adult, maintenance	3.0 to 3.5	5.0 to 6.0
	Horse, growing		
diet primarily based on forages	Mare, early gestation	3.5 to 4.0	6.0 to 7.0
mixed diet (forage + concentrate)[1]	Mare, early lactation	4.5	10.0 to 11.0
diet primarily based on forages	Mare, late lactation	4.0	9.0 to 10.0
mixed diet (forage + concentrate)[1]	Horse, light work[2]	3.0 to 4.0	6.0 to 7.0
	Horse, medium work[2]	4.0	8.0 to 9.0
	Horse, intense work[2]	4.5 to 5.0	9.5 to 10.5

[1] Diet containing at least 15-20% of concentrate feeds.
[2] See Chapter 6: feeding working horses.

Table 2.8. Drinking water characteristics (adapted from the Netherlands Commission on Animal Research and Feeding (1973), in Löwe and Meyer, 1979).

Criteria	Safe	Possible toxicity	Pollutant source
pH	6.0-7.5	<2 and >11	industrial pollution
Hydrogen sulphate	If negative test	If positive test	bacterial activity, degradation of organic matter
Ammonium	<2 mg/l	>3 mg/l	bacterial activity, degradation of organic matter
Nitrates	-	>30 mg/l	pollution by organic compounds
Nitrites	-	0.5 mg/l	
Iron	<0.2 mg/l	>3 mg/l	
Salt (Na Cl)	<2 g/l	>8 g/l	pollution by surface water
Sulphate	-	>250 mg/l	
Faecal bacteria: *Colibacilla*, *Streptoccocus*, *Salmonella*	only with a negative test		waste pollution

2.5 Minerals and vitamins supplementation

2.5.1 Macrominerals and trace elements

Mineral supplementation must be adapted to the composition of the diet and requirements of horses. Minerals must be allocated with respect to a Ca:P ratio approximating 1.5 in order to prevent bone problems from developing. Moreover, an excess of calcium in the diet will reduce the absorption of other minerals, such as magnesium or the trace elements (zinc, manganese, copper and iron). The

Table 2.9. Upper concentration limits (mg/l) of elements in drinking water potentially toxic to horses (Adapted from the Canadian Council of Ministers of the Environment, 2002).

Aluminium	5
Arsenic	0.025
Boron	5
Cadmium	0.08
Chromium	0.05
Cobalt	1
Copper[1]	0.5-5
Fluoride	1-2
Lead	0.1
Mercury	0.03
Molybdenum	0.5
Nickel	1
Selenium	0.05
Vanadium	0.1
Zinc	50

[1] A lower limit for sheep and cattle and a higher limit for pigs and poultry.

importance of the provision of copper and zinc must also be recognised in respect to maintaining a Zn:Cu ratio of 4 to 6.

Traditional horse feeds are often low in calcium (except for legume forages), sodium and magnesium. On the other hand they are often rich in potassium. Calcium content of many concentrate ingredients is low, cereals in particular having a very low Ca:P ratio of 0.2 to 0.5. Phosphorus content of mature forages is quite limited, and very low in beet pulp (Ca:P is 13:1) and corn silage (Chapter 16, chemical composition tables and Chapter 12, the nutritional value of feeds).

The digestion coefficients of minerals is high in horses (Chapter 1, Table 1.14) and is dependent on the nature of the supplement. One needs to be aware of the amount of phytate phosphorus located in cereal hulls (bran) and poorly digested by horses (Chapter 12).

To satisfy recommended intakes for each type of horse (see the tables, Chapters 3 to 8) a supplement must be provided that is adapted to the composition of the diet and the horse's requirements. Mineral supplements must be incorporated into the ration since, with the exception of salt (sodium chloride), horses are not very good at consuming minerals when offered free choice. On the other hand horses are very efficient users of the salts of calcium and phosphorus; the most common and least costly sources (Chapter 16, Appendix 3).

2.5.2 Vitamins

Horses are unable to efficiently use plant carotenoids, the natural precursors of Vitamin A. The preferred means of supplementation is to use coated vitamin A. Excess vitamin A is to be avoided as is the use of cod liver oil which may produce a vitamin E deficiency.

Supplementation efficiency depends upon the condition of the liver and kidneys as well as thyroid function. Excessive intake of vitamin D should also be avoided as that may increase bone lesions. Five to 10 times more vitamin A than vitamin D should be provided along with sufficient calcium and phosphorus supplementation. Dry yeasts, which are well tolerated by horses, are the best sources for vitamin B supplementation.

2.6 Principal feeding problems and their prevention

Feeding problems, for the most part, are due to errors in diet formulation. Problems due to feeding are numerous and often difficult to diagnose (Table 2.10).

2.6.1 Disorders linked to feeding management

2.6.1.1 Digestive health

Changing diets

The digestive ecosystem is an environment in structural (microbial composition) and functional (enzyme activity secreted by cells of the digestive tract and microorganisms) equilibrium corresponding to given environmental conditions, primarily the nature and quantity of the feeds consumed. Any abrupt changes in these conditions either quantitative or qualitative will result in many disturbances: changes in the composition and number of microorganisms ordinarily present and their enzymatic activity, proliferation of pathogenic microbes (*Salmonella, Clostridia, Colibacteria*) in acute cases, exceeding the capacity of the mucosa to process ingesta and absorb nutrients released during the digestive process. These disturbances cause problems that show up as diarrhoea and/or colic and laminitis, liver overload from self-intoxication or enterotoxaemia and in extreme cases, enteric septicaemia. If there is a change in the type of feed, diet composition, proportion of forage to concentrates or amount fed, the change must be made gradually and with care. The relatively small size of the stomach, the short amount of time ingesta remains in the stomach and small intestine and the relatively long time it spends in the large intestine are the reasons for this cautious transition.

For example, when the diet is changed from hay to silage or a cereal rich component is introduced or the composition of the diet is altered (i.e. the proportions of forage to concentrate change) these alterations must be gradual. In the adult horse such changes should take place over at least a week with an increasing amount of concentrate added to, or replacing the dry forage base. The duration of change is multiplied by 2 to 3 when the change involves switching from dry forage to silage. In young horses, where the variety of forages offered is often large, the diet transition should always be 2 to 3 weeks and even longer in the very young horse. With foals transition will start a month before

Table 2.10. Pathologies of nutritional origin or aggravated by feeding errors.

Type of error or imbalance		Common causes	Clinical symptoms
Characteristics of an inadequate diet (unsatisfactory feed composition)	excess bulk (cellulose)	eating too much straw or poor quality forage	colic[1], blockage of the digestive tract
	insufficient fibre	insufficient forage bulk, use of non-edible bedding	colic[1], diarrhoea or constipation
		incorrect choice of compound feeds	
	excess protein	incorrect compound feed. too much high quality legume forage	colic[1], laminitis[2], reduced performance
	calcium deficiency and/or excess phosphorus	too much cereal grains without balancing for calcium content and/or low quality forage	osteopathies leading to lameness, bone spavin
	selenium and vitamin E deficiency	soil deficiencies that are reflected in forage	white muscle disease in foals
			mau lead to myoglobinuria in adult
	vitamin A deficiency	traditional diet (hay and oats) not adequately balanced for nutrients	slow growth, problems of bone growth
Presence of toxic elements in the diet[3]	intoxication by poisonous plants	consuming plants outside of pasture areas	Chapter 9, Table 9.8
	mycotoxicoses	straws or grains altered by moulds (mould contamination not readily visible)	specific symptoms for each type of mycotoxin (Chapter 9, Section 9.3.2)
	feed additives included in the diet that are toxic to horses (momensin, narrasin, lasalocid)	concentrate feed manufacturing error.	difficult death (Chapter 9, Section 9.2.5)
		feeding horses concentrate feed designed for beef cattle	
	pesticides	careless spraying of crops, accidental contamination	specific symptoms for each product
Feed allergies	dust, moulds, various allergens (e.g. pollen)	very dusty or mouldy forages or concentrate feeds	pulmonary emphysemas (heaves)
			hives 'crisis hives', blisters on the body
Meal feeding errors	too much feed during non-working periods	sudden return to work after a rest period in which concentrate feeding was not reduced	paralysing myoglobinuria manifested by sudden, significant weakness
	rapid, over-consumption of grains	feeding errors or horses gaining access to feed storage areas	diarrhoea, acute dilatation of the stomach causing severe colic with strenuous vomiting efforts, laminitis[2]
	long term over-feeding	over-weight foals on pastures rich in high protein forage	laminitis[2]
	irregular meal times	missed feedings, schedules not followed	colics[1]
	too rapid consumption of concentrate feeds	hungry horses or bolting feed	oesophageal obstruction
Watering errors / characteristics of abnormal water	irregular or inadequate watering	no automatic waterers; clogged waterers	colic[1]
	rapid drinking of a large quantity of cold water	thirsty horses following work	colic[1] or laminitis[2]
	water contaminated with soil of sand		colic[1]

[1] Colics: clinical symptoms are severe abdominal pain in horses. They are caused by intestinal spasm or abnormal stomach dilatation. They can be complicated blockages resulting in rapid mortality. Not all colics are of gastrointestinal origin.
[2] Laminitis: a very serious condition due to congestion of the laminar tissue between the hoof bones and wall. Acute laminitis causes very severe foot pain preventing any movement by the horse. In the chronic form there is a displacement of the 3rd phalanx and possible loss of the hoof.
[3] More information on toxicological problems may be obtained from the National Centre for Veterinary Toxicological Information, National Veterinary School of Lyon, (now VetSgroSup), Lyon, France. Similar reference laboratories should be consulted in other countries.

weaning with the supplementation of a concentrate feed and will last for a month after weaning when dry forages or silage can be introduced (Chapters 3 to 8).

Diets overly rich on concentrates

A diet overly rich in cereal grains can produce a lactic acidosis condition in the large intestine, which is often accompanied by the release of toxic amines. Such digestive changes may produce diarrhoea or constipation colic.

Diets based on silages

Horses may be fed these diets if the rules of harvesting-storage-feeding are followed (Chapters 9 and 11). Wilted silages or those dried to 30 to 35% DM, or wilted and wrapped silages dried to 50% DM generally cause few problems as long as guidelines are followed. On the other hand, direct cut silages with less than 30% DM are often a source of problems. Intakes are limited and/or variable, faeces are wet (silages are too high in water and/or poorly preserved) or, alternatively too dry (if silage contains too much starch). All this produces a dysfunction of the microflora in the hindgut with various consequences. Excess ammonia in silage results in an alkalization of large intestine contents which in turn favours the proliferation of a putrefying alkaline microflora with the resulting production of amines coming from the decarboxylation by the microflora of amino acids released in the feed digestion process. These amines (histamine, tyramine and tryptamine) have powerful pharmacodynamic properties that may explain the various observed pathologies: Intestinal congestion and the production of pathogenic microbes, muscular or foot problems due to pseudo-allergenic reactions (i.e. histamine-like). Ammonia intoxication can also increase production of microbial endotoxins as it stimulates the development of pathogenic microflora. So far ammonia content of silages should definitely not exceed 10% of total N content whereas soluble N is lower than 50% of total N (Chapter 11, Table 11.1). Excess lactic acid may contribute to diarrhoea development, stasis colic and changes in the intestinal mucosa, which may eventually allow the absorption of bacterial endotoxins. The lactic acid content in silages should be moderate for such reasons (<5 g/kg DM, Chapter 11, Table 11.1)

Diets with a high straw content

Horses can be fed a diet with limited quantity of straw, up to 3 kg, without problems if supplemented with 6 to 7 kg of concentrate and 1.5 kg of hay while housed on artificial bedding. However, if the straw is provided free choice horses can develop colic due to intestinal blockage.

Beet pulp

Dehydrated beet pulp is a frequent feed component, often included in compound supplements, which reduces the possibility of swelling and stomach blockage due to drinking and salivation after eating if fed alone. It may be fed alone if crushed due to its hardness, and fed over 3 meals as long as water is available free choice (e.g. automatic waterer).

2.6.1.2 Food borne parasitism

The role of feeds in parasitism is ambivalent. Feeds are often the source of parasites. Quality feeds can also play a role in protecting against infestation by allowing horses to develop a protective immune response.

Sites of parasites

A listing of parasites is provided in Table 2.11. The information contained is a compilation of the work of several authors. These parasites are common. The digestive tract is a principal site of these parasites. Diseases identified with the principal parasites provide an understanding of possible connections with feeds and performance.

Table 2.11 Principal internal parasites of horses (adapted from Gawor, 1995; Kilani *et al.*, 2003; Rehbien *et al.*, 2002; Soulsby, 1987).

Organs	Type of parasites	Genus
Digestive tract	Trematodes	*Gastrodiscus* spp.
	Cestodes	*Anoplocephala* spp.
	Nematodes	Parascaris
		Draschia
		Strongyloides
		Small *Strongylus* (*Cyathostomes*)
		Large *Strongylus*
		Oxyuris
	Arthropods	*Gasterophilus* (larvae)
	Protozoa	Giardia
		Eimeria
		Cryptosporidium
Liver	Trematodes	Dicrocoelium
		Fasciola
	Cestodes	Cysticercus tenuicollis
		Hydatic cysts
Cardiovascular system	Nematodes	Strongylus
	Protozoa	Babesia
		Trypanosoma
Respiratory system	Nematodes	Dyctiocaulus
	Cestodes	Hydatic cysts (*Echinococcus granulosus*)
Muscles and tendons	Nematodes	Onchocerca
		Trichinella
	Protozoa	Sarcocystis
Eye	Nematodes	Thelazia
		Setaria

Parasites and diseases of food origin

This is the most frequent source of infection.

- Parasites associated with intake of mare's milk (*Strongyloides westeri*). This nematode is found in the foal's small intestine. If infected, diarrhoea may commence starting at 10 days of age. Diagnosis is made by faecal flotation of helminth eggs. Transmission via the mare's milk is most common and prevention requires treatment of mares throughout the foaling period, for example with the anthelmintics ivermectine or oxibendazole 24 hours after foaling.
- Parasites transmitted on pasture through grazing:
  - Cestodes. If infestation is heavy the foal will have an unthrifty appearance and anaemia will be present. Frequent ulceration of the mucosa occurs at the site of attachment of *Anoplocephala perfoliata*. This parasite may be responsible for intestinal perforations, peritonitis and colic. An anthelmintic used to control nematodes is also effective against *A. perfoliata* (at a double dosage of 13.2 mg/kg BW of pyrantel pamoate).
  - Nematodes
    - *Cyathostome larvae.* These are identified by acute symptoms of weight loss accompanied by severe diarrhoea, especially at the end of winter and in spring in horses under 5 years. Neutrophilia and hypoalbuminemia are present in affected horses. Lesions consist of typhlitis, and colitis with congestion, ulceration and necrosis of the mucosa. Diagnosis cannot be made by faecal flotation of helminth eggs as it is the larval stages that cause the lesions.
    - Strongylosis with *Strongylus.* Complex cycles with lengthy migrations lasting several months are typical (Chapter 10, grazing management). Serious lesions due to the migrations are important and different depending upon the *Strongylus* species. *Strongylus vulgaris* is an arterial strongyle due to its migration through the arteries while *Strongylus edentatus* is hepato-peritoneal and *Strongylus equinus* is hepato-pancreatic. Adult worms (bloodsucking) also have pathological impact causing anaemia, diarrhoea and emaciation of the horse.
    - *Trichostrongylus axei.* This small nematode is also capable of infecting ruminants. This small parasite causes chronic catarrhal gastritis, with nodular lesions with thickened mucosa and encapsulated areas of congestion leading to weight loss.
- Parasites transmitted by consuming bedding, straw or grass. Cycles may be observed outside on pasture as well as in the stable.
  - *Ascaris*. Foals gradually become infected after birth; harbouring adult worms from the age of 4 to 5 months. A diagnosis can be made by faecal flotation. In heavy infestations migrating larvae produce respiratory signs (summer colds). Adult worms can cause foals to be unthrifty and occasionally develop colic, through intestinal obstruction and perforations.
  - Pinworms. Adult *Oxyuris* (pinworms) frequently cause irritation of the perineum. This irritation results in the horse rubbing the anal area vigorously leading to hair loss in the area.
- Parasites transmitted by eating feeds contaminated with meat. *Trichinella* in horses has been a source of contamination for humans on several occasions. Infestation in horses is not well documented but probably occurs through the involuntary consumption of contaminated meat of mammalian origin.

Non-food parasites transmitted by insect vectors

Gastrophilus (Bot flies) are the source of moderate gastritis. Larval migration following skin infestation sometimes causes stomatitis. Diagnosis is difficult as it is dependent on the presence of larvae located in the stomach, but sometimes found in faeces.

Heavy infestation of *Habronema* cause catarrhal gastritis. *Draschia* may cause lesions with a tumour appearance of up to 10 cm diameter. Larvae of these two nematodes were found in the lungs of foals with *Rhodococcus* abscesses. Clinical signs are seen upon granuloma rupture. Diagnosis by eggs in faecal material is difficult due to the small size of the eggs.

Feeding and resistance to parasites

The influence of diet quality has been studied in ruminants (especially in sheep). Good quality and feed quantity play protective roles against parasitic infestation. No studies of this type are available in horses. One study on colics in horses indirectly shows an association between parasites and feeding. The presence of parasites (*Strongyles* and *Anoplocephala*) is a significant factor but key elements as well are changes in feeding practices in the stables and individual differences (some horses are prone to repeated colics). Badly managed changes in feeding practices are an important factor leading to parasite infection as a general rule. Individual factors are equally important in resistance to strongyle infestation. On first principles, feeding a quality diet will reduce disease incidence (colic) and possibly parasitic infestation, especially in horses that are most susceptible to infestation.

2.6.1.3 Bone health

Osteo-articular pathologies are more insidious. They may be caused by errors in mineral and/or vitamin feeding or by an over feeding of energy.

Osteofibrosis

This is the most severe and most common problem related to incorrect calcium-phosphorus balance. It is prevalent in young horses (yearlings or slightly older horses) rather than adults. Osteofibrosis occurs when there is a deficiency of calcium and most frequently, an over-supply of phosphorus. Diets rich in grains can produce such conditions as can the excess use of bran mashes, or feeding mediocre quality forage lacking in legumes or the wrong choice of a mineral supplement. Providing vitamin D without correcting the calcium supply is equally problematic. It should not be forgotten that not only must the minimum amount of calcium be supplied according to recommended feeding tables (Chapters 3 to 8) but the correct Ca:P ratio of 1.5:1 must also be approximated to 'offset' where appropriate an excessive intake of phosphorus.

Rickets

Rickets are caused by a defective supply of calcium and/or phosphorus along with a deficiency of vitamin D. It is, in fact, relatively rare in horses in comparison with osteofibrosis. However, it is wise to be cautious concerning phosphorus intake especially in growing animals, whenever the forage consumed is of low quality or when feeding ingredients low in phosphorus (dehydrated beet pulp for example).

Osteomalacia occurs under the same conditions as rickets, but affects bone that have reached maturity and which undergo inadequate remineralization. Significant bone deformation may occur under such conditions.

Osteochondrosis

This problem occurs during the first year of life in foals that receiving energy rich diets in order to obtain maximum growth. The target rate of growth should not exceed that indicated in Chapter 5. Even in this case the proportion of grains in the diet should not be more than 40%. The intake ratios of calcium and phosphorus or copper and zinc need to be maintained close to 1.5:1 and 4 to 6:1 respectively.

2.6.1.4 Muscular health

White muscle disease

Selenium deficiency is due to a deficiency of selenium in forage, which reflects a soil deficiency of this element. This can be corrected by providing selenium containing mineral supplement or by injecting selenium compounds into the pregnant or lactating mare. Intakes must be carefully regulated as excess intake can cause very serious selenium toxicity. Providing vitamin E in conjunction with selenium has an additive effect. Applying selenate enriched fertiliser to fields destined to produce hay or winter barley has been tested and shown to be successful in increasing selenium intake.

Exertional rhabdomylosis (tying-up)

This problem is a result of intramuscular hyper-accumulation of lactic acid following high muscular activity (e.g. sprinting) by a horse on a high grain diet. Metabolism of excess glycogen stored in muscle due to such diet induces a severe acidosis, which results in a malfunction in muscle metabolism with a further result of the excretion of myoglobin in urine. In prevention, the quantity of cereals in the ration must be limited and the workload adjusted to an appropriate level.

2.6.1.5 Others

Laminitis

Laminitis is most often a consequence of a combination of factors: a diet too rich in cereal grains, possibly associated with excess protein, and eventually aggravated by a sudden change in the feeding regime. It is, therefore, very important to limit diet energy and protein concentrations, make any dietary changes very carefully and adjust feed intake to actual work intensity.

Change in appetite: increased fatigability

Chronic lack of sodium chloride intake can lead to a change in appetite, a rough appearance to the hair coat or early onset of signs of fatigue during exercise. An excess of sodium chloride is unusual.

2.6.2 Related to feeds

Feeds must be free from toxic plants, moulds and bacterial toxins and preservatives used in feeds for other species (Chapter 9). These risks are avoided if proper forage harvesting and preservation techniques (Chapter 11) and the correct manufacture and storage of concentrate feeds (Chapter 9) are followed.

2.6.3 Supplementation of minerals, trace elements and vitamins

Supplementation of diets based on forages is necessary to balance the diet and prevent deficiencies. But it must not be excessive in order to prevent possible health problems (Chapter 1), or toxicities, which may sometimes be fatal. Daily intake limits of minerals, trace elements and vitamins are given in Tables 2.12 and 2.13.

2.7 Special feeding behaviours

2.7.1 Coprophagy

This behaviour is natural and frequently observed in young foals. It normally disappears about the age of one month when the microbial activity in the hindgut is sufficiently developed. But it can also persist, with less frequency over several months. Coprophagy can, therefore, have an effect on examination for parasites: contaminated adult faeces, if ingested, will lead to an identifiable excretion

Table 2.12. Daily intakes limits for minerals and trace elements (adapted from NRC, 1989, 2005, 2007).

Elements	Per kg dry matter intake	NRC
Calcium	2% (and P sufficient, Ca/P ≤ 2)	2005, 2007
Phosphorus	1% (Ca sufficient, Ca/P ≤ 2)	2005, 2007
Magnesium	0,8%	2005, 2007
Potassium	1% (but *ad libitum* watering)	2005, 2007
Sodium chloride	6% (but *ad libitum* watering)	2005, 2007
Sulphur	0,5%	2005
Copper	250 mg (and Zn/Cu 4 to 6)	2005, 2007
Zinc	500 mg (and Zn/Cu 4 to 6)	2005, 2007
Cobalt	25 mg	2005, 2007
Selenium	0,5 mg	2007
Iron	500 mg	2005, 2007
Iodine	5 mg	2005, 2007
Manganese	500 mg/day	2007
Chromium	3000 mg (oxide form) et 100mg (trivalent form)	2005
Fluorine	40 mg	2005
Silicon	?	2007

Table 2.13. Daily intake limits for vitamins (adapted from NRC, 1989, 2005, 2007).

	Per kg	NRC
Vitamin A	16,000 UI/kg DMI	1989, 2007
β carotene[1,2]	?	2007
Vitamin D	44 UI/kg BW	1989, 2007
Vitamin E	1000 UI/kg DMI	1989, 2007
Vitamin K	requirements ×1000	2007
Thiamine[2]	?	1989, 2007
Riboflavin[2]	?	2007
Niacin[2]	?	2007
Biotin[2]	?	2007
Folate[2]	?	2007
Vitamin C[2]	?	2007

[1] 1 mg β carotene = 400 UI vitamin A.
[2] ? = not observed for other vitamins.

of eggs by foals. The interpretation of faecal examinations conducted on foals and their mothers should be highly discussed.

Coprophagy in adults is unusual and is considered a behaviour problem possibly due to boredom, a deviation of taste, or the provision of a diet containing too much concentrate.

2.7.2 Wood chewing

A stabled horse will frequently chew wooden troughs or feed bunks. High concentrate diets frequently result in this particular behaviour. Provision of straw especially in bedding can reduce this problem.

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Chapter 3. The mare

William Martin-Rosset, Michel Doreau and Daniel Guillaume

Most of the mares foal in winter or early spring (from February to May) and suckle their foals for 6 months at least in temperate and cold zones. They winter outdoor (heavy and leisure breeds) or indoor (race and sport breeds) and then turn out to pasture in the spring. Foals are weaned in autumn. Weaning weight and development depend primarily on age and hence on date of birth.

Biological efficiency of mares is low compared to other nursing farm animals. Currently, heavy and leisure breeds are fed at a minimum cost. When forage is scarce they must mobilise body reserves to meet demands. Pasture is therefore the most important source of nutrients, which enables mares to recover weight and body condition. In addition, the mare's maximum milk yield occurs at pasture when the greatest demand for nutrients for the mare- foal unit arises and mating for the next foaling takes place. In contrast, race and sport breeds are always fed to meet their requirements throughout the annual reproductive cycle and to wean heavy and well developed foals ready to be subjected to intensive or semi-intensive raising and training systems for race and sport breeds respectively.

3.1 Annual reproduction cycle

3.1.1 Gestation-lactation cycle

Mares usually begin the breeding process at 3 years of age, often later for Thoroughbred and Trotter mares and sometimes at 2 years for draft breed fillies. Full growth will not have been achieved at this time (Chapter 5). Foaling will generally take place in spring (close to when pasture becomes available) except for racing breeds for which it begins in late winter. Fertilisation takes place in the month following parturition or at the next heat when reproduction is well underway.

Mares nurse their young for 5 to 7 months depending on the breed. The drying off of the mare, which corresponds to weaning of foals takes place at the end of summer or in autumn.

3.1.2 Elements of reproductive physiology

3.1.2.1 Seasonality

Foaling takes place naturally, primarily in spring and early summer, since the ovarian activity of the mare is seasonal. From an administrative point of view the racing societies register the age and competitive categories of horses from January 1. Foals conceived during the same breeding season have, therefore the same administrative age while the true age may be different by several months depending on the date of conception. This could therefore be an advantage or a handicap depending on when the horse enters athletic competition, at 2 years for race horses, or the live weight attained at weaning for commercial draft horse foals.

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The period of ovarian activity is centred on the period of the longest days of the year: spring – summer. The onset and duration of ovarian activity parallels the duration of increased light or photoperiod. Artificial light can be used to advance the initiation of ovarian activity and ovulation in our latitudes (e.g. temperate zone). A lighting program of 14.5 hours of light alternating with 9.5 hours of dark starting near the end of December is required.

In spring, the date that starts the reproductive season depends on physiological state of the mare and her body condition. Young mares (3-4 years) or mares that lack condition (score <3; Chapter 2, Table 2.2) and those that have nursed a foal during the previous year systematically show a period of winter ovarian inactivity. On the other hand, a significant proportion of mature mares in good body condition and who have not nursed during the previous year will show continuous ovarian activity. The winter cessation of ovarian activity is, therefore, a consequence of the energy balance of the mare. In spring, mares that have received a concentrate feed supplement will ovulate earlier than unsupplemented mares. This effect is due to the provision of energy and protein but also depends on the quality of the protein.

The level of nutrient intake, especially in the fall, influences the initiation of ovarian activity and reduces the period of inactivity to 40 days in mares that are well fed vs 190 days for malnourished mares (Figure 3.1).

The effect of supplementation and lengthening of the photoperiod early in the year on reproductive activity has also been documented. In other words, the classic photostimulation of 14.5 hours of light for thin mares does not advance the date of first ovulation unless it is accompanied by an increased level of nutrient intake.

3.1.2.2 Reproductive cycle

The sexual cycle has a duration of 20 to 30 days and is divided into 2 phases: the follicular phase and the luteal phase, respectively, characterised by a plasmatic concentration of progesterone close to

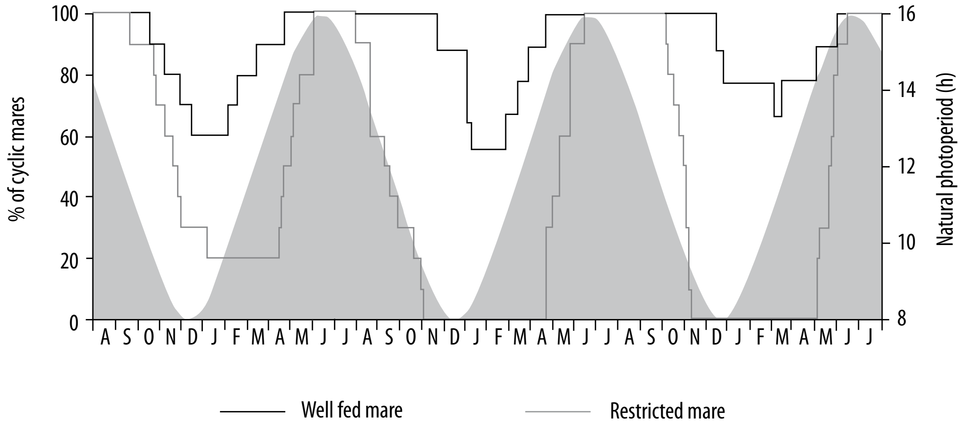

Figure 3.1. Effect of nutrient intake on mare cyclicity (Salazar-Ortiz *et al.*, 2011).

zero or elevated (Figure 3.2). Follicular growth commences during the luteal phase and ends, under the impetus of FSH, in ovulation. During this phase of follicular growth oestrus behaviour, or heat (behaviour during which the mare will accept the stallion) is induced by oestrogen secreted by the developing follicle, begins on average 6 days prior to ovulation and ends the day following ovulation. Following ovulation plasma progesterone concentrations increase linearly until plateauing 5 days after ovulation. This concentration is maintained until either pregnancy occurs or it starts to decrease if pregnancy is not successful (Figure 3.2).

The nutritional state of the mare influences follicular growth. The latter is much more active in mares in good body condition (score >3) than in thin mare (score <3). The sexual cycle is shorter in mares in good body condition, than in thin mares. This nutritional effect is primarily under control of the GH-IGFI system. It seems to be possible, therefore, to have mares, initially in poor body condition,

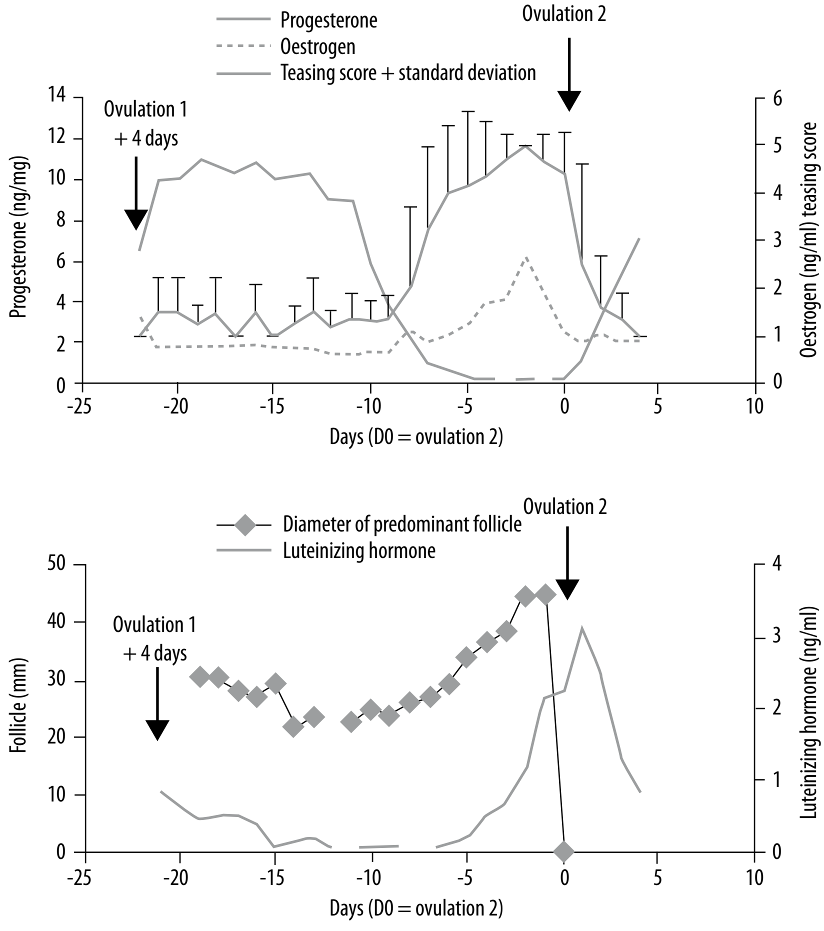

Figure 3.2. Characteristic of ovarian cycle of mares and principal hormones involved (Briant *et al.*, 2006). Mean of 10 mares with a typical evolution of the sexual receptivity corresponding to a typical ovarian cycle.

become reproductively successful if, during a period of 4 to 6 weeks, through improved nutrition they can be returned to an adequate body condition score.

3.1.2.3 Puberty

First ovulation occurs on average about 15 months of age in fillies, which also indicates age at puberty. However, this age can vary from 9 months to 3 years respectively in fillies that are well fed or restricted and depending on environmental conditions, particularly nutritional and seasonal interaction.

3.1.2.4 Pregnancy

On average, pregnancy last for 340 days. Variability in duration accounts for much of the variation in birth weight. Maintenance of pregnancy is a result of the secretion of maternal progesterone in early stages but after the 5^{th} month depends on placental progesterone secretion.

During gestation foetal weight increase is a function of the mare's physiological state. From conception to 5-6 months, cellular multiplication is intense, but weight is limited (Figure 3.3). After this point foetal weight gain is rapid. At the same time the associated tissues, placenta and chorionic tissues surrounding the foetus, and the maternal tissues of the uterus and udder, also undergo considerable development in order to respectively ensure nutrition of the foetus *in utero* and postnatal nutrition of the new-born foal.

3.1.3 Practical consequences

Control of ovarian inactivity is critical on one hand to increasing the number of usable cycles during the breeding season to enable the mare to conceive. On the other hand it is important to have the foal born at a date that will allow the foal to reach an age appropriate for its ultimate use (e.g. racing) or optimum bodyweight at weaning for ideal marketing (draft). The appropriate level and quality of feed consumed by the mare during the gestation-lactation cycle will allow her to attain optimal body condition (3.0 to 3.5).

Gestation is one of two periods of the gestation-lactation cycle during which the foetal tissues develop. The mare's feed intake must be such that proper foetal development and continuing good health of the foal during the post natal period is assured (Chapter 5).

3.2 Nutrient requirements

Requirements were established using the factorial method (Chapter 1). Requirements for production are added to those for maintenance in both physiological situations: gestation then lactation to obtain total requirements.

3.2.1. Maintenance requirements

Protein requirements are fixed at 2.8 g MADC/kg $BW^{0.75}$.

Energy requirements for maintenance are strictly set at 0.0373 UFC/kg $BW^{0.75}$. This amount may be adjusted higher or lower depending on the breed (Chapter 1, Table 1.1). This basic requirement is increased according to three factors:

1. Physical activity. Movement and activity is more and more important as space available to mares increases. Increases in energy expenditure range from 10 to 25% when mares are outside during winter.
2. Climate. Draft horse mares are normally housed outdoors throughout the year and are most often in a thermal neutral environment (-10 °C to +25 °C, Chapter 1) in temperate latitudes. Above and below these limits expenditures are increased by 2.5% per degree Celsius. Energy expenditure by race horse, sport or leisure riding mares are not increased since they are housed in conditions that seldom expose them to temperatures outside the thermal neutral zone.
3. Physiological state. Late pregnancy and especially the start of lactation result in an increase on maintenance costs related to a general increase in the mare's metabolism. Information from other species indicates that the increase varies according to level of production, however, the quantitative importance of this in the mare has not been documented. Draft horse mares frequently begin breeding at 75% of their adult weight, about 2 years of age, while other breeds begin at 85% of adult weight at 3 years of age. During the year following breeding they continue to gain 200 to 300 g/day. From Chapter 5 it can be seen that the cost of growth corresponds to a daily energy capture of 750 kcal of net energy and 50 g of protein, however, this is taken into account when calculating total daily requirements.

Mineral requirements calculated per kilo of bodyweight are: 0.040 g for calcium, 0.025 g for phosphorus, 0.015 g for magnesium, 0.020 g for sodium, and 0.060 g for potassium on the principles discussed in Chapter 1.

The maintenance requirements for micronutrients are expressed per kg of dry matter consumed: 10 mg for copper, 50 mg for zinc, 40 mg for manganese, 40 mg for iron, 0.2 mg for cobalt, 0.2 mg for selenium, and 0.2 mg for iodine.

Requirements for vitamins are also expressed on a per kg dry matter consumed basis: 3,250 IU for vitamin A, 400 IU for vitamin D, and 60 IU for vitamin E.

3.2.2 Pregnancy requirements

Gestation is a crucial period in the reproductive cycle of the mare as she must produce a healthy foal at the right time of the year depending on the breed in question. She must also be in good body condition at foaling in order to conceive again when bred during the following month.

3.2.2.1 Growth of the conceptus: foetal and maternal tissues in the reproductive cycle

There is only a small increase in weight of the foetus during the first 5 months of gestation. This changes during the last 180 days of gestation (6 to 11 months) when weight increase is elevated and is linear throughout the last 4 months (Figure 3.3A).

The Meyer and Ahlswede (1976) curve was primarily used to establish the weight for age relationship of the foetus over the last 6 months of gestation (6 to 11 months) in light breeds. Several models

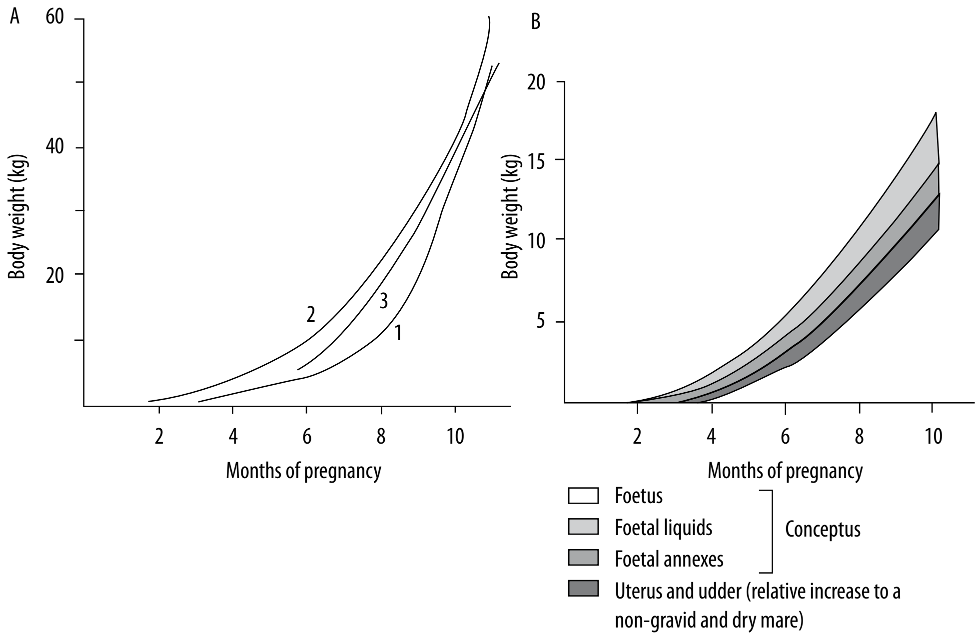

Figure 3.3. Changes during gestation in the weight of (A) the foetus (adapted from (1) Dusek, 1966; (2) Den Engelsen, 1966; (3) Meyer and Ahlswede, 1976), and (B) associated tissues, uterus and udder of the mare.

were developed from bodyweight of the foetus determined by Meyer and Ahlswede (1976). Data were discarded in respect of their particular biological status (aborted foals; non-viable foals and bodyweight inconsistent with age along the chronological series of data). Three models were established for predicting bodyweight of the foetus from days of gestation. R^2 of exponential, power and polynomial models were 0.941, 0.947 and 0.981, respectively. The comparison of the subsequent adjustment and the analysis of the residue between adjusted value and residual value using the three models show that the polynomial model is the most accurate one:

$$\text{BW foetus (kg)} = 17.38 - 0.2885\ \text{Age} + 0.001197\ \text{Age}^2 \qquad n=16 \qquad R^2=0.981$$

Where BW is bodyweight and Age is days of gestation. Bodyweight of the foal estimated at birth is 55.6 kg at foaling, when using this model, which is highly consistent with original data and routine data observed for light breeds. It accounts for 10.1% of dam weight. Bodyweight of the foetus predicted at each month of gestation using this model was then estimated as a percentage of dam weight.

This method was also used for estimating bodyweight of the foetus at corresponding months of gestation in heavy breeds (Martin-Rosset and Doreau 1984a; Martin-Rosset *et al.*, 2006a). Another polynomial model is proposed for draft mares because the range of body size of those breeds is much larger than for light breeds (650 to 900 kg BW) and average bodyweight of foal at birth is very different (67 kg BW) as well. This model is based on data of foetus collected at INRA during the last 5 months of pregnancy (Martin-Rosset, unpublished data).

$$Y = -1.99 + 13.67X - 37.87X^2 + 45.41X^3 - 18.34X^4 \qquad n=21 \qquad R^2=0.892$$

$$Y = \frac{\text{Foetus bodyweight over 5 last months of gestation}}{\text{Foal bodyweight at birth (= 67 kg)}} \times 100$$

$$X = \frac{\text{Number of days from conception date}}{\text{Average duration of gestation (= 340 days)}} \times 100$$

Placenta and foetal membranes (products of conception), uterus and udder (maternal tissues) and foetal liquids that develop during gestation, on average develop more rapidly than the foetus (Figure 3.3B). They represent 70% of the conceptus at mid-gestation and only 45% at parturition. Throughout gestation the weight of the udder doubles while the uterus increases 20-fold.

Requirements are therefore calculated according to changes in weight of conceptus, that is, foetus and foetal membranes weights plus the change in weight of maternal tissues.

3.2.2.2 Quantity of nutrients contained in the gravid uterus

The quantity of nutrients contained in the conceptus (e.g. foetus + foetal membranes) can be calculated from its weight increase and its chemical composition. Foetal lipid and protein quantities at various stages change, respectively, from 1.9 to 2.6% and from 10.3 to 17.1% between the 6th and 11th months of gestation while calcium and phosphorus vary from 60 to 67 g and 35 to 36 g/kg of foetal DM. There is very little variation in other minerals. The chemical composition of foetal membranes and maternal tissues is considered to be similar to that of the foetus at the same stage of gestation. Under these conditions it has been estimated from bibliographic weight data on weight changes of foetal membranes and maternal tissues and their chemical composition, that accumulation of nutrients in these tissues, respectively, represent on average, 20 and 10% of the increase in the nutrients of the foetus.

Gestation requirements are, therefore, calculated from foetal weight gain and changes in chemical composition (Table 3.1) multiplied by 1.3 to take into account requirements associated with foetal membranes and maternal tissues.

Table 3.1. Foetal weight gain and chemical composition (adapted from Meyer and Ahlswede, 1976).

Month	Weight gain (% of birth weight)	Energy (kcal/kg liveweight)	Protein	Minerals (g/kg dry matter)				
				Ca	P	Mg	Na	K
6-7	14	850	10.5	60	35	1	11	10
8-9	19	1,050	12.5	65	35	1	9	8
10	23	1,180	15.3	67	36	1	8	8
11	25	1,280	17.1	67	36	1	7	7

The total quantity of energy stored by the conceptus and maternal tissues ranges from 35 kcal/100 kg BW to 156 kcal/100 kg BW and the requirement is calculated by dividing this stored energy by the efficiency of energy utilisation: 25%. The requirement ranges from 138 kcal/100 kg BW to 627 kcal/100 kg BW or 0.06 UFC/100 kg BW to 0.28 UFC/100 kg BW using the updated reference value for barley of 2,250 kcal/kg (Chapter 1, Section 1.3.2).

Similarly the amount of protein deposited in the conceptus and maternal tissues range from 7 g/100 kg BW to 26 g /100 kg BW. The requirement calculated considering the efficiency of digestible protein utilisation as 55% ranges, therefore, from 13 g MADC/100 kg BW to 47 g MADC/100 kg BW.

Mineral requirements of gestation are calculated from the foetal chemical composition and assuming, as for energy and protein requirements, the related weights of foetal membranes and maternal tissue growth. Mineral digestibility has been reported elsewhere (Chapter 1, Table 1.14). Mineral requirements for gestation per 100 kg BW range from 0.9 to 4.3 g for calcium; 0.8 to 3.5 g for phosphorus; 0.03 to 0.08 g for magnesium; 0.10 to 0.25 g for sodium and 0.12 to 2.7 g for potassium.

Requirements for trace elements are expressed per kg of dry matter intake. These concentrations are provided in Chapter 2, Table 2.1. Vitamin requirements are also expressed per kg of dry matter intake (Chapter 2, Table 2.1).

3.2.2.3 Total requirements of the gestating mare

Total requirements are the sum of maintenance (X_1) and gestation (X_2) requirements (Tables 3.6 to 3.11).

Energy (UFC/d) = (X_1[1] UFC/100 kg BW × BW kg) + (X_2 UFC/100 kg BW × BW kg)

Protein (g MADC/d) = (X_1 g MADC/100 kg BW × BW kg) + (X_2 g MADC/100 kg BW × BW kg)

Minerals (g/d) = (X_1 g/kg BW × BW kg) + (X_2 g/kg BW × BW kg)

Trace elements (mg/d) = mg/kg DM × Y kg of TDMI[2]

Vitamins (IU/d) = IU/kg DM × Y kg of TDMI

3.2.4 Lactation

Lactation is the second major period in the mare's reproductive cycle. Mares must adequately nourish their foals in order that they attain 45% of their adult weight at weaning. It is also important that the mare conceive again during the first month after foaling, so that a 12 month interval between foaling is maintained. This is especially important in the sport horse breeds but in all breeds it is important that foaling date meets the production objectives of the particular breed.

[1] Increase by 5 to 10% respectively for light horse breeds.

[2] TDMI = total dry matter intake.

3.2.4.1 Physiology

The mare's udder is located in the inguinal position. It consists of 4 distinct glands, two situated on each side of a median line. Each pair of glands is served by one teat. Two cisterns and two ducts empty into each teat. Mammary tissue or parenchyma consists of two tissue types: secretary and ejection. Secretary tissue consists of cells surrounding an alveolus into which milk is secreted. The alveoli are surrounded by myoepithelial cells which, when contracting force milk ejection into a network of ducts that lead to the cisterns located at the base of each teat. The udder has an average limited capacity of 2 litres of milk, 75 to 85% of which is stored in the alveoli.

During the reproductive cycle the udder undergoes a cycle of growth and differentiation that occurs in three phases: growth of the udder during gestation; secretion of milk during lactation and involution during or while undergoing weaning. All of these changes are under hormonal control. During gestation alveolar tissue develops at the expense of adipose tissue under the influence of elevated concentrations of progesterone and oestrogen. High progesterone concentration inhibits milk production.

Reduction in progesterone concentration towards the end of gestation accompanied by increases in prolactin are controlling factors in the initiation of lactation. The mechanism by which progesterone blocks lactation is not absolute as some mares will prematurely secrete milk during the week prepartum. The term 'candling' refers to the process of secreted milk coagulating at the end of mare's teats. Lactational anoestrus does not normally occur following foaling and follicular growth followed by ovulation begins during the first week postpartum.

Prolactin plays a principal role in lactogenesis and the initiation of lactation. Plasma prolactin concentration increases during the days leading to foaling and reaches a maximum at parturition. It remains elevated for the first three months of lactation. There is a positive correlation between foal nursing behaviour and plasma prolactin concentration.

Milk ejection from the udder is initiated by oxytocin, secreted from the posterior lobe of the pituitary gland, whose release is mechanically stimulated by the foal's nursing action.

As the foal's nursing demands decrease primarily after the 3rd to 4th month of lactation, the mare's udder begins the continuing process of involution. Increased intramammary and alveolar pressure caused by milk accumulation combined with the effects of inhibitors probably contained in milk lead to the suppression of milk secretion. Involution leads to the replacement of mammary parenchymal tissue by adipose and connective tissue. Weaning procedures are important in prevention of mastitis and intramammary inflammation due to distensions of the mammary gland.

3.2.4.2 Milk production

Milk production varies from 2.0 to 3.5 kg/100 kg of bodyweight which translates to daily production of 10 to 17 kg for a light horse mare of 500 kg and from 14 to 25 kg for draft mares weighing 700 kg during the first 3 months of lactation. Production is higher in nursing mares than in mares that are milked.

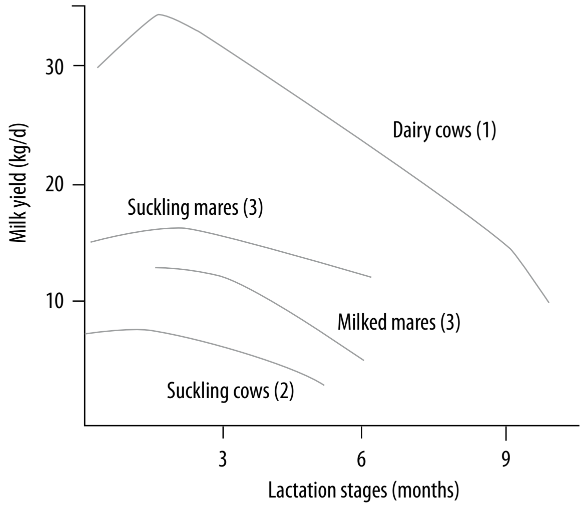

Figure 3.4. Lactation curves for nursing or milked mares and for nursing or milked dairy cows (Doreau and Martuzzi, 2006a). Data from (1) Faverdin *et al*. (1987); (2) Le Neindre *et al*. (1976); (3) calculated using data of bibliography and Wood's (1967) model.

Peak lactation occurs between the 2nd and 3rd month postpartum and persistence is high throughout lactation in the nursing mare (Figure 3.4). There is no difference in milk production between light breed mares and draft mares when production is expressed on a per 100 kg BW basis. In contrast, milk production is higher in mares of small breeds of less than 450 kg (Chapter 8). Within the light horse (Anglo-Arab and Selle-Francais) or draft types (Breton and Comtois, or other draft breeds) there is no difference in milk production when expressed per 100 kg BW. However, individual variation is high in all breeds as there has been no selection on this criterion. Variability may also be due to the growth potential of the foal.

Milk production is similar between 1st and 2nd lactations. However, it does increase with age up to 10 to 15 years. Milk production is dependent on feed intake and body condition of the mare. Increasing energy intake has a positive effect on milk production if the mare has a body condition score less than 3, no matter what the composition of the diet (50 to 95% hay and 5 to 50% concentrate feeds) if the diet is fed free choice, especially if the diet is forage based and for a specified period. The effect is even greater if body condition is poor (less than 2.5) as such mares are unable to mobilise sufficient body reserves to meet demand. In contrast, the level of energy intake has little effect if body condition is good (score >3.0). Milk production does increase with dietary protein content up to 14%.

3.2.4.3 Milk composition

Mares' milk is low in dry matter, 100 to 120 g/kg, in fat, 10 to 20 g/kg, in total protein, 20 to 35 g/kg, but relatively high in lactose, 55 to 65 g/kg. Gross energy content varies from 479 to 598 kcal/kg (Figure 3.5). Mares' milk contains only 5 g/kg of minerals (Table 3.2) but is rich in vitamin C.

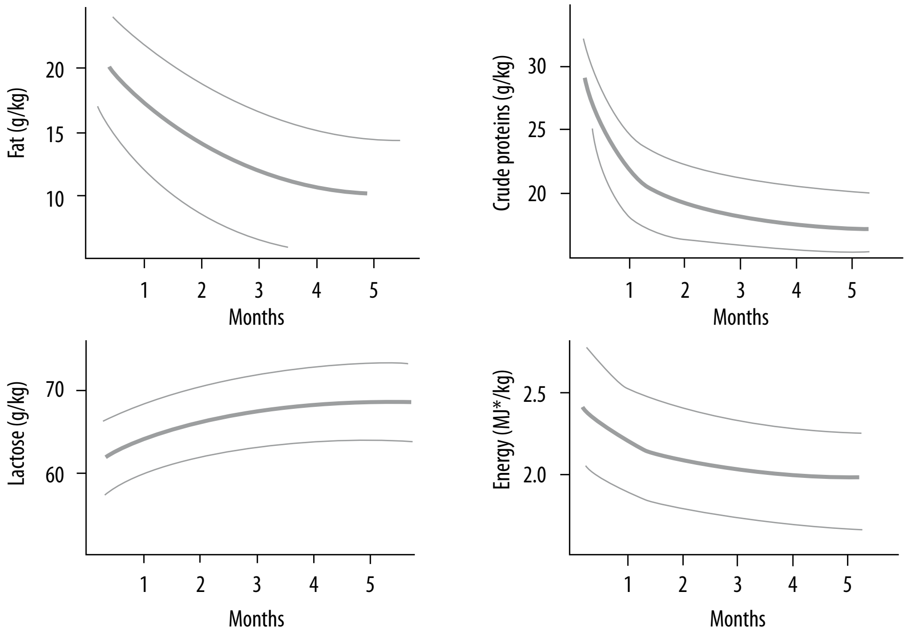

Figure 3.5. Variation in composition of mare's milk with stage of lactation (Doreau and Martin-Rosset, 2002). * MJ = Megajoule..

Table 3.2. Mineral and trace element composition of mares' milk (Doreau and Martin-Rosset, 2002).

Minerals (g/kg)	
Calcium	0.5-1.3
Phosphorus	0.2-1.2
Magnesium	0.04-0.11
Sodium	0.07-0.20
Potassium	0.3-0.8
Chloride	0.2-0.6
Sulphur	0.22
Trace elements (mg/kg) (principal)	
Copper	0.2-1.0
Zinc	0.9-6.4
Manganese	0.01-0.05
Iron	0.22-1.46
Iodine	0.004-0.042
Molybdenum	0.02

Milk fat in mares' milk accounts for 50% of its total energy. Fat is enclosed in globules with a diameter of 2-3 µm. They are primarily composed of triglycerides (80%), but also of fatty acids (9-10%) and phospholipids (5-19%). Fatty acid composition is typical for a monogastric herbivore consuming forages from which the fat content is digested and absorbed in the small intestine (Table 3.3). Milk fat is rich in polyunsaturated fatty acids, linoleic acid and α-linoleic acid, but also in short and medium chain acids (45%), palmitic acid in particular. However, stearic acid content is low.

Total milk protein is rich in casein and whey proteins but non-protein nitrogen is limited (Table 3.4). The non-protein nitrogen fraction is composed of 50% urea and 50% amino acids and peptides. Casein is represented by 3 casein groups: α, β and k. Whey proteins contain lactalbumins (61% α, β) of mammary origin, one serum albumin (4.4%), immunoglobulins (19.8%) from blood, but also proteo-peptones, lysozyme (6.6%), transferrin and lactoferrin (8.2%).

Milk composition varies with stage of lactation (Figure 3.5). Fat content, especially long chain fatty acids, protein, in particular immunoglobulins, varies considerably during the colostrum period which has a duration of 12 to 24 hours.

Table 3.3. Fatty acid composition of mares' milk fat (adapted from Doreau and Martuzzi, 2006b).

Fatty acids		Proportion (average %)
C4:0	butyric acid	0.6
C6:0	caproic acid	0.7
C8:0	caprylic acid	3.1
C10:0	capric acid	7.2
C12:0	lauric acid	7.6
C14:0	myristic acid	7.5
C14:1 n-5	myristoleic acid	0.7
C15:0	pentadecanoic acid	0.4
C15:1	pentadecenoic acid	0.4
C16:0	palmitic acid	20.8
C16:1 n-7	palmitooleic acid	5.6
C17:0	margaric acid	0.4
C17:1	heptadecenoic acid	0.4
C18:0	stearic acid	1.2
C18:1 n-9	oleic acid	19.8
C18:2 n-6	linoleic acid	11.3
C18:3 n-3	linolenic acid	11.9

Table 3.4. Main fractions of mare's milk protein (adapted from Malacarne *et al.*, 2002).

Total Protein		Whey proteins		Casein		NPN[1] × 6.38	
g/kg	%	g/kg	%	g/kg	%	g/kg	%
21.4	100	8.3	38.8	10.7	50.0	2.4	11.2

[1] NPN = non-protein nitrogen.

Fat and protein contents decrease from 15-25 g/kg to 5-15 g/kg and from 25-30 g/kg to 5-10 g/kg, respectively, while lactose content increases from 55-60 g/kg to a plateau at 65 g/kg towards the 3rd month of lactation. No negative relationship has been observed between production level and fat content.

Breed has little effect on milk fat composition, while the effect on fat content is not known. However, the protein content may be higher in light breeds than in draft breeds. Casein proportion of total protein appears to be higher in riding breeds than in the Haflinger breed.

The concentration and composition of milk, especially fat and protein, can be influenced by the mare's dietary regimen. Fat content and short and medium chain fatty acids are considerably reduced when the proportion of concentrate feed in the diet is increased. However, the fat content is elevated and linoleic acid content is 5 times greater when mares are on pasture in the summer compared to those that are housed indoors and fed mixed diets. Linoleic acid content is increased if mares are supplemented with lipids (maize, soybean, or sunflower oils). Fat and fatty acid contents can also be increased and short and medium chain fatty acids decreased if energy intake exceeds requirements. This is a result of the dilution effect due to increased milk production. Protein supplementation has contradictory effects on protein content for reasons that have not yet been discovered. However, protein supplementation with soybean meal will increase milk protein content. Lactose content is reduced in mares fed a hay based diet compared to those on a mixed regimen. Contents of copper, zinc and iron cannot be modified by supplementation with these minerals.

3.2.4.4 Metabolism of the principal milk constituents

The principal milk constituents originate from two sources: the nutrients provided by dietary ingredients and those supplied by body reserves (Chapter 1, Figure 1.10). Lactose comes from glucose absorbed in the small intestine.

Fats are partially derived from fatty acids absorbed in the small intestine and partly from *de novo* synthesis in the mammary gland. The absorbed fatty acids are not isomerised or hydrogenated as they are in ruminants. Consequently the composition of milk fat with respect to long chain fatty acids is similar to that of the diet. Precursors of *de novo* synthesis are certain volatile fatty acids, acetate and 3-hydroxybutyrate, which come from the forage cell wall digestion in the hindgut. Propionate, also coming from hindgut digestion is not a fatty acid precursor. Palmitic acid comes from both *de novo* synthesis and absorption from the small intestine. Fatty acids unsaturated at C18 come primarily from dietary sources and/or body reserves.

Total milk protein content as protein and non-protein nitrogen decreases when dietary protein intake is below requirements. Conversely, the urea content of milk is elevated when dietary protein increases since more ammonia is produced from increased protein degradation in the hindgut, which is then recycled via the endogenous urea cycle.

3.2.4.5 Requirements

Lactation requirements were evaluated per kg of milk produced because of the great variation among individuals of similar size and even greater among different sized mares. Reference values for milk production for different months of lactation have essentially come from data produced by INRA using markers and from the literature. They are expressed per 100 kg BW (Table 3.5). The reference values for energy, total protein and minerals have likewise been obtained from literature data as well as those of INRA.

Energy requirements were calculated from the gross energy content of milk as indicated in Table 3.5 and using the efficiency of utilisation of energy of 65%. Energy requirements per kg of milk therefore vary from 0.29 to 0.23 UFC/kg between the 1^{st} and 6^{th} month of lactation.

Protein requirements per kilo of milk were calculated from the total protein content given in Table 3.5 and using the efficiency of utilisation of protein of 55%. Protein requirements per kg of milk vary from 44 to 22 g MADC over the same interval.

Mineral requirements were evaluated from milk content as given in Table 3.5 and using the digestibility of the various elements as provided in Chapter 1, Table 1.14. Lactation mineral requirements expressed per kg of milk therefore vary from 1, 4 to 2.4 g for calcium, from 1.4 to 2.3 g for phosphorus, from 0.11 to 0.22 g for magnesium, from 0.12 to 0.18 g for sodium and 6.8 to 9.6 g for potassium. Trace element requirements are expressed per kilo of dry matter intake. Concentrations are identical to those given for gestation and presented in Chapter 2, Table 2.1. Requirements for vitamins are also expressed per kg of dry matter intake and presented in Chapter 2, Table 2.1.

3.2.5 Total requirements of the lactating mares

Total requirements are the sum of maintenance (X_1) and lactation (X_2) requirements (Tables 3.6 to 3.11).

Energy (UFC/d) = (X_1 UFC [3]/100 kg BW × BW kg) + (X_2 UFC/kg milk × milk yield kg/d)

Protein (g MADC/d) = (X_1 gMADC/100 kg BW × BW kg) + (X_2 g MADC/kg milk × milk yield kg/d)

Minerals (g/d) = (X_1 g minerals /kg BW × BW kg) + (X_2 g minerals/kg milk × milk yield kg/d)

Trace elements (mg/d) = mg/kg DM × Y kg TDMI [4]

Vitamins (UI/d) = UI/kg DM × Y kg TDMI

3.2.6 Intake capacity

Mares are able to meet their needs from a primarily forage based diet. The daily dry matter voluntarily consumed varies with the palatability of the diet and the physiological state of the mare as seen in Figure 3.6.

[3] Increase by 5 to 15% respectively for light horse breeds.

[4] TDMI: total dry matter intake.

Table 3.5. Reference values for milk production and composition.

Month	Production[1] (kg/j/100 kg BW)	Milk composition[1]		Minerals[2]			
		Energy (kcal/kg)	Protein (g/kg)	Ca (g/kg)	P (g/kg)	Mg (g/kg)	Na (g/kg)
1st	3.0	545	24	1.20	0.80	0.10	0.16
2nd	3.3	512	21	0.90	0.60	0.07	0.14
3rd	3.2	468	20	0.90	0.60	0.07	0.14
4th	2.9	455	16	0.70	0.50	0.05	0.11
5th	2.2	431	12	0.70	0.50	0.05	0.11
6th	2.0	431	12	0.70	0.50	0.05	0.11

[1] Doreau *et al.* (1990, 1992, 1993) and a literature survey by Doreau and Martin-Rosset (2002).
[2] Literature reviews by Doreau *et al.* (1990), Schryver *et al.* (1986), and Smolders (1990).

The quantity of material consumed is greater when the forage provided *ad libitum* is good quality hay compared with straw: 2.0 vs 1.4 kg DM/100 kg BW during gestation, and 3.1 vs 2.6 kg DM/kg BW during lactation for hays having a crude fibre content of 28-32% vs 35-38%.

Ingested quantities decreased between 10 to 30% during the latter period of gestation due to the negative effect of conceptus growth on abdominal capacity. Digestibility of organic matter decreased by 5 points as food retention was reduced by 30% (Chapter 1, Table 1.6). These results have been taken into account in the evaluation of feed intake recommendations. In lactation intake quantities increase sharply by 25 to 50% during the first month following foaling and plateau in the following

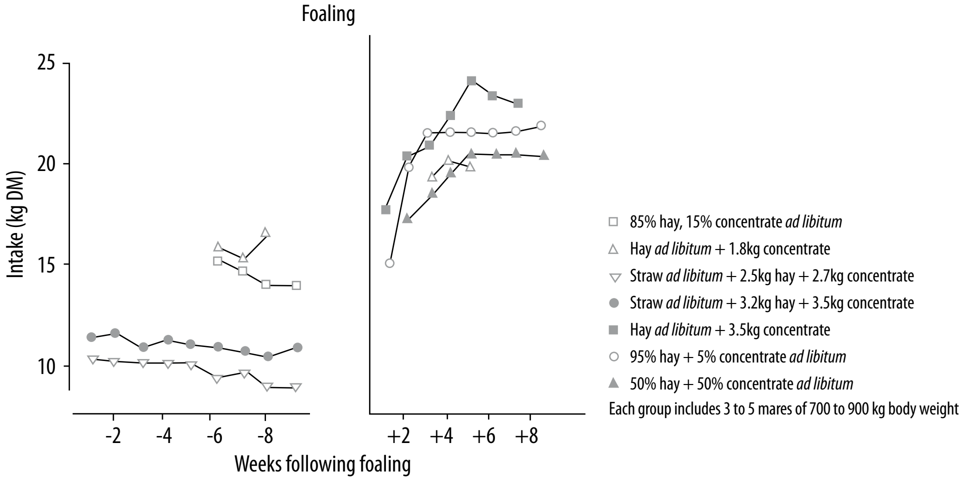

Figure 3.6. Changes in consumption of different forage based diets in draft breed mares at the end of gestation and start of lactation (Martin-Rosset and Doreau, 1984b; Martin-Rosset *et al.*, 2006b). Three to five mares of 700 to 900 kg bodyweight in each group.

months. Diet digestibility is not influenced by this large variability even though feed retention may be slightly reduced (Chapter 1, Table 1.6).

The amounts consumed also vary with the size of the mare: they are slightly greater in small size, about 10% on average, when compared with large size even when expressed on a per 100 kg BW basis. Individual variability in consumed quantities is increased by 5 to 15% in gestation and lactation by the nature of the forage. The variability is even greater when the diet is supplemented with a higher proportion of concentrate feed.

When fed *ad libitum*, forage quantities consumed decrease as the proportion of concentrate in the diet increases. The substitution rate on average is -1.2 kg of forage (hay) for each supplementary kg of concentrate added to the diet (Chapter 1, Section 1.2.3.3).

Consumption expressed as kg DM/100 kg BW is not significantly different between primiparous and multiparous mares. In contrast, consumed quantities are closely related to the body condition of the mare at foaling. The amounts consumed are much greater in thin mares, especially in lactation in order to compensate for the initial energy deficit (Figure 3.7). Consumption by entirely free range mares is, on average, 20% greater in comparison with stabled mares principally because of climatic conditions, especially in winter, and because of physical activity (movement, interaction).

3.3 Recommended allowances

Recommended allowances were developed from feeding trials conducted at INRA according to principals outlined in Chapter 1.

3.3.1 Variation in bodyweight

During the annual reproductive cycle the mare's bodyweight varies from 15 to 20% under normal management conditions (Figure 3.8).

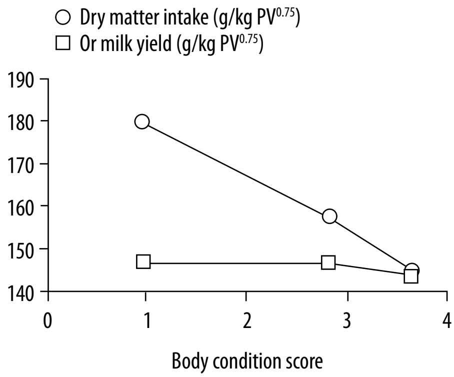

Figure 3.7. Effect of body condition on *ad libitum* consumption and milk production during the first months of lactation (adapted from Doreau *et al.*, 1991, 1993).

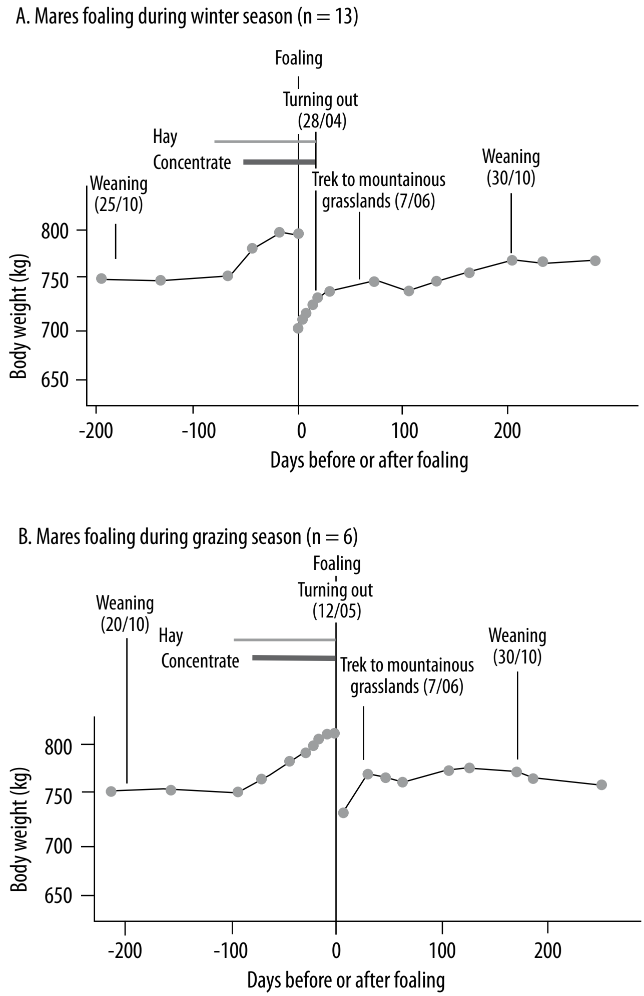

Figure 3.8. Variation in bodyweight of mares throughout the reproduction cycle (A) stabled, (B) on pasture (adapted from Martin-Rosset *et al.*, 1986a,b).

Bodyweight is at maximum and minimum before and after foaling, respectively. During the latter months of gestation weight gain is between 2 and 15% of BW in well fed mares but this doesn't change much if the mare is slightly underfed (draft horse mares in the mountain zone or leisure horse mares on range land). At foaling the weight loss ranges from 12 to 15% depending on diet. Products of conception and digestive tract contents represent 85-90 and 10-15% of this loss respectively (Figure 3.9). After foaling the mare will gain 5 to 6% on normal diets and body condition (score of 3.0-3.5). This variation is due to increased feed intake and, consequently, digestive tract contents, depending on diet composition (Figure 3.9). The mare's weight gain is more significant if feeding is plentiful, on pasture for example (Figure 3.8B), or if body condition is less than ideal (score <3).

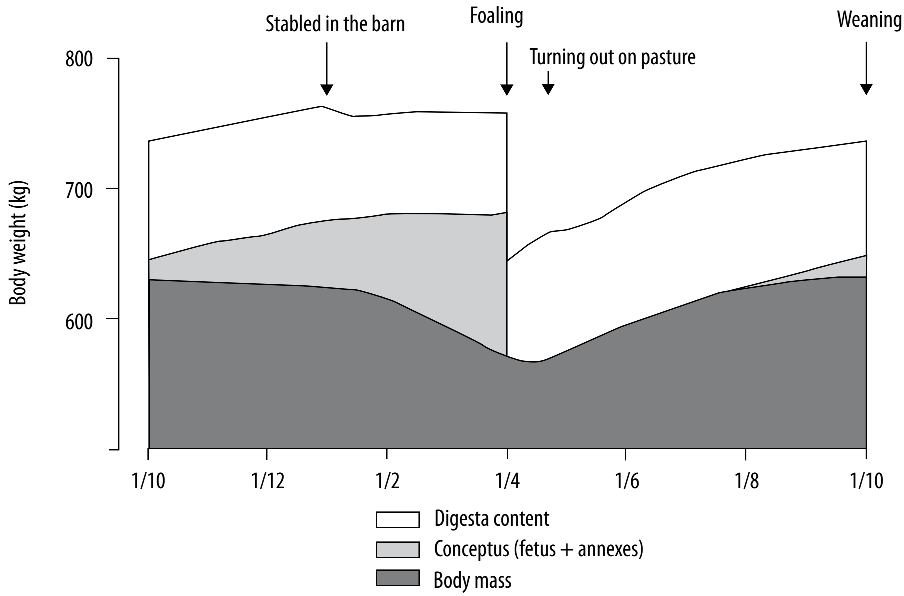

Figure 3.9. Changes in composition of the mare's bodyweight during the reproductive cycle (this figure schematises the estimated changes of body mass, conceptus and digestive contents of a mare managed, successively, indoors and on pasture, fed free choice, except during the last two months of gestation).

3.3.2. Role of body reserves

The proportion of fat tissues in the mare's carcass can range from 8 to 14% depending on body condition (2.5< score <4.0); which represents 20 to 70 kg of reserves in a mare weighing 500 kg (Chapter 1). The importance of the reserves is primarily linked with level of feed intake.

In all situations the objective is to have at foaling a foal that has normal bodyweight and vitality and then will have an excellent growth rate due to sufficient, perhaps maximum, milk production. This situation is especially desirable in mares from the racing and sport horse breeds. For economic reasons draft mares and those of leisure activities are often restricted during the winter season.

Moderate energy restriction (20%) at the end of gestation leading to a condition score of 2.5 at foaling does not have a negative effect on foal weight or vitality if the mare has a condition score of 3.5 and 3.0 respectively, when drying off at the end of October and at the start of winter (6-7th month of gestation). However, feed intake after foaling must be sufficient to allow the mare to rapidly regain a condition score of 3.0 to 3.5 at the end of the first month of lactation and to ensure that the foal has a satisfactory growth rate. In fact the mare has the ability to release energy from body reserves and use that provided in the diet as long as body condition is ≥2.5 at foaling, to ensure normal foetal growth and maintenance of a minimum condition.

Similarly, the number of ovarian cycles required to fertilize the mare and the fertility rate, are much less or higher, respectively, if body condition is adequate (score ≥3.0) or not (score <3.0) at foaling.

A similar effect may be obtained in mares with a lower score (≥2.5) at foaling later during the first month of lactation if feed intake is high.

3.3.3. Feed and nutrient intakes

Total feed intake changes with the mare's physiological state: dry, non-pregnant mares (maintenance) and/or at the start of gestation (0-5th month), pregnant or lactating mares and those still growing as are fillies foaling for the first time at 3 to 4 years of age as with draft or light horses respectively.

Recommended feed intakes can be:

- For racing and sport horse breeds, precisely equal to nutritional requirements previously established (Section 3.2.3 and 3.2.5) with the exception of particular leisure breeds that can be managed like draft mares for economic reasons.
- For draft breeds to be temporarily below requirements: the limited feed intake column vs the normal feed intake column, if it is considered that the mare can, depending on her body condition at drying off (or foal weaning), mobilise body tissues without harm.

Recommended feed intakes are presented in separate tables representing in one section the light horse breeds (racing, competitive sport and recreation) and in another the draft breeds. Light breeds are in the 450 to 600 kg range depending on size (Tables 3.6 to 3.9) and the draft breeds from 700 to 800 kg for the most common sizes (Tables 3.10 and 3.11).

Dry matter consumption values given in the tables does not represent the maximum dry matter quantity that mares can consume. Rather they are the dry matter quantities that will meet their needs. Moreover this quantity depends on the nutritional value of the diet (type of forage, proportion of concentrate). These are the reasons for minimum and maximum consumption values for each physiological situation. Maximum values represent forage based diets and minimum values are for diets high in concentrates. All intermediate values are acceptable.

Variations to take into account particular situations in the footnotes to each table: body condition score, primiparous, mares for recreational purposes that may need to increase intake. Concerning those who may be managed entirely outdoors and may eventually need to increase consumption due to climatic conditions, refer to Chapter 1, Section 1.2.1.

3.4 Practical feeding

3.4.1 Strategies according to the type of mare in use

The annual reproduction cycle and feeding management of mares in use is specific to each goal of production: racing, competitive sport, recreational and draft.

3.4.1.1 Racing

Foaling takes place in winter since horses race breeds at 2 years of age. These mares are in a situation where the end of gestation is in winter and lactation commences at the end of winter and early spring;

Table 3.6. Recommended daily nutrient allowances and intake allowances for light horse mares with an adult bodyweight of **450 kg**.[1]

Physiological state	kg milk/d	Daily nutrients allowances																			Dry matter intake[2] (kg)
		UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (IU)	Vit. D (IU)	Vit. E (IU)	
Mare, dry or in early lactation		3.8	274	25	18	13	7	9	36	27	75	375	1.5	1.5	300	600	1.5	24,400	3,000	450	6.5-8.5
Mare, pregnant[3,4]																					
0-5 months		3.8	274	25	18	13	7	9	36	27	75	375	1.5	1.5	300	600	1.5	24,400	3,000	450	6.5-8.5
6th month		4.1	330	30	22	17	7	9	36	27	78	390	1.6	1.6	310	620	1.6	32,800	4,700	620	6.5-9.0
7th month		4.3	333	30	24	18	7	9	36	27	78	390	1.6	1.6	310	620	1.6	32,800	4,700	620	6.5-9.0
8th month		4.5	351	32	26	19	7	10	36	28	78	390	1.6	1.6	310	620	1.6	32,800	4,700	620	6.5-9.0
9th month		4.7	382	35	30	23	7	10	36	28	83	415	1.7	1.7	330	660	1.7	34,900	5,000	660	7.0-9.5
10th month		5.0	453	41	34	26	7	10	36	29	88	440	1.8	1.8	350	700	1.8	37,000	5,300	700	7.0-10.5
11th month		5.1	485	44	37	29	7	10	36	29	93	465	1.9	1.9	370	740	1.9	39,100	5,600	740	7.5-11.0
Mare, lactating[3]																					
1st month	13.5	7.8	868	70	50	44	10	12	43	70	120	600	2.4	2.4	480	960	2.4	45,600	7,200	600	10.5-13.5
2nd month	14.9	7.9	838	74	45	38	9	12	43	70	130	650	2.6	2.6	520	1,040	2.6	49,400	7,800	650	11.5-14.5
3rd month	14.4	7.4	792	73	44	37	9	12	43	68	130	650	2.6	2.6	520	1,040	2.6	49,400	7,800	650	11.5-14.5
4th month	13.1	7.0	653	68	36	31	8	11	42	59	120	600	2.4	2.4	480	960	2.4	45,600	7,200	600	10.5-13.5
5th month	9.9	6.1	492	58	32	27	8	10	41	58	105	525	2.1	2.1	420	840	2.1	39,900	6,300	525	9.5-11.5
6th month	9.0	5.9	472	55	31	26	8	10	41	57	85	425	1.7	1.7	340	680	1.7	32,300	5,100	425	7.5-9.5

[1] Bodyweight 24 h after a normal foaling.

[2] The lowest values are for diets high in concentrates, the highest are to maximise forage consumption.

[3] An additional intake of 0.5 UFC and 25 g MADC is recommended for fillies bred at 3 years.

[4] Mares for recreational purposes may be fed at 90% of their energy requirements if their body condition score at the 6th month of gestation is 3 or more.

Table 3.7. Recommended daily nutrient allowances and intake allowances for light horse mares with an adult bodyweight of **500 kg**.[1]

Physiological state	kg milk/d	Daily nutrients allowances																			Dry matter intake[2] (kg)
		UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (IU)	Vit. D (IU)	Vit. E (IU)	
Mare, dry or in early gestation		4.1	296	27	20	14	8	10	40	30	80	400	1.6	1.6	320	640	1.6	26,000	3,200	480	7.0-9.0
Mare, pregnant[3,4]																					
0-5 months		4.1	296	27	20	14	8	10	40	30	80	400	1.6	1.6	320	640	1.6	26,000	3,200	480	7.0-9.0
6th month		4.4	359	33	25	18	8	10	40	30	83	413	1.7	1.7	330	660	1.7	34,700	5,000	660	7.0-9.5
7th month		4.7	361	33	27	20	8	10	40	30	83	413	1.7	1.7	330	660	1.7	34,700	5,000	660	7.0-9.5
8th month		4.9	381	35	29	21	8	11	40	31	83	413	1.7	1.7	330	660	1.7	34,700	5,000	660	7.0-9.5
9th month		5.1	416	38	34	25	8	11	40	31	88	438	1.8	1.8	350	700	1.8	36,800,	5,300	700	7.5-10.0
10th month		5.4	495	45	38	28	8	11	40	32	93	463	1.9	1.9	370	740	1.9	38,900	5,600	740	7.5-11.0
11th month		5.5	530	48	41	32	8	11	40	32	98	488	2.0	2.0	390	780	2.0	41,000	5,900	780	8.0-11.5
Mare, lactating[3]																					
1st month	15,0	8.5	956	77	56	49	11	13	47	78	133	663	2.7	2.7	530	1,060	2.7	50,350	8,000	660	11.5-15.0
2nd month	16,5	8.7	923	82	50	42	10	13	47	78	143	713	2.9	2.9	570	1,140	2.9	54,950	8,550	710	12.5-16.0
3rd month	16,0	8.2	872	80	49	41	10	13	47	76	143	713	2.9	2.9	570	1,140	2.9	54,150	8,550	710	12.5-16.0
4th month	14,5	7.7	717	75	41	35	9	12	46	66	133	663	2.7	2.7	530	1,060	2.7	50,350	8,000	660	11.5-15.0
5th month	11,0	6.7	538	63	36	30	9	11	45	65	118	588	2.4	2.4	470	940	2.4	44,650	7,050	600	10.5-13.0
6th month	10,0	6.5	516	60	34	28	9	11	45	64	98	488	2.0	2.0	390	780	2.0	37,050	5,850	490	8.5-11.0

[1] Bodyweight 24 h after a normal foaling.

[2] The lowest values are for diets high in concentrates, the highest are to maximise forage consumption.

[3] An additional intake of 0.6 UFC and 30 g MADC is recommended for fillies bred at 3 years.

[4] Mares for recreational purposes may be fed at 90% of their energy requirements if their body condition score at the 6th month of gestation is 3 or more.

Table 3.8. Recommended daily nutrients allowances and intake allowances for light horse mares with an adult bodyweight of **550 kg**.[1]

Physiological state	kg milk/d	Daily nutrients allowances: UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (IU)	Vit. D (IU)	Vit. E (IU)	Dry matter intake[2] (kg)
Mare, dry or in early gestation		4.4	318	29	22	16	8	11	44	33	85	425	1.7	1.7	340	680	1.7	27,700	3,400	510	7.5-9.5
Mare, pregnant[3,4]																					
0-5 months		4.4	318	29	22	16	9	11	44	33	85	425	1.7	1.7	340	680	1.7	27,700	3,400	510	7.5-9.5
6th mointh		4.8	387	35	28	20	9	11	44	33	85	425	1.7	1.7	340	680	1.7	35,700	5,100	680	7.5-10.0
7th month		5.1	390	35	30	22	9	11	44	33	85	425	1.7	1.7	340	680	1.7	35,700	5,100	680	7.5-10.0
8th month		5.3	412	37	32	24	9	12	44	34	85	425	1.7	1.7	340	680	1.7	35,700	5,100	680	7.5-10.0
9th month		5.5	450	40	37	28	9	12	44	34	93	463	1.9	1.9	370	740	1.9	38,900	5,600	740	8.0-10.5
10th month		5.8	537	49	42	31	9	13	44	35	98	488	2.0	2.0	390	780	2.0	41,000	5,900	780	8.0-11.5
11th momth		6.0	576	51	46	35	9	13	44	35	103	513	2.1	2.1	410	820	2.1	43,100	6,200	820	8.0-12.0
Mare, lactating[3]																					
1st month	16.5	9.3	1,044	84	61	54	12	14	52	86	145	725	2.9	2.9	580	1,160	2.9	55,100	8,700	725	12.5-16.5
2nd month	18.2	9.5	1,008	89	55	47	11	14	52	83	158	788	3.2	3.2	630	1,260	3.2	59,850	9,450	790	14.0-17.5
3rd month	17.6	8.9	952	87	54	46	11	14	52	81	158	788	3.2	3.2	630	1,260	3.2	59,850	9,450	790	14.0-17.5
4th month	16.0	8.4	781	82	44	38	10	13	51	73	145	725	2.9	2.9	580	1,160	2.9	55,100	8,700	725	12.5-16.5
5th month	12.1	7.4	544	69	40	33	10	13	51	72	128	638	2.6	2.6	510	1,020	2.6	48,450	7,650	640	11.5-14.0
6th month	11.0	7.1	560	65	38	31	10	12	50	71	108	538	2.2	2.2	430	860	2.2	40,850	6,450	540	9.5-12.0

[1] Bodyweight 24 h after a normal foaling.

[2] The lowest values are for diets high in concentrates, the highest are to maximise forage consumption.

[3] An additional intake of 0.6 UFC and 30 g MADC is recommended for fillies bred at 3 years.

[4] Mares for recreational purposes may be fed at 90% of their energy requirements if their body condition score at the 6th month of gestation is 3 or more.

Table 3.9. Recommended daily nutrient allowances and intake allowances for light horse mares with an adult bodyweight of **600 kg**.[1]

Physiological state	kg milk/d	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (IU)	Vit. D (IU)	Vit. E (IU)	Dry matter intake[2] (kg)
Mare, dry or in early gestation		4.8	339	31	24	17	9	12	48	36	90	450	1.8	1.8	360	720	1.8	29,300	3,600	540	8.0-10.0
Mare, pregnant[2,4]																					
0-5 months		4.8	339	31	24	17	9	12	48	36	90	450	1.8	1.8	360	720	1.8	29,300	3,600	540	8.0-10.0
6th month		5.2	414	38	30	22	9	12	48	36	93	463	1.9	1.9	370	740	1.9	38,900	5,600	740	8.0-10.5
7th month		5.5	417	38	33	24	9	12	48	36	93	463	1.9	1.9	370	740	1.9	38,900	5,600	740	8.0-10.5
8th month		5.7	441	40	35	26	9	13	48	37	93	463	1.9	1.9	370	740	1.9	38,900	5,600	740	8.5-10.5
9th month		6.0	482	44	40	30	9	13	48	37	100	500	2.0	2.0	400	800	2.0	42,000	6,000	800	9.0-11.0
10th month		6.3	578	53	46	34	9	14	48	38	105	525	2.1	2.1	420	840	2.1	44,100	6,300	840	9.0-12.0
11th month		6.5	620	56	50	38	10	14	48	38	110	550	2.2	2.2	440	880	2.2	46,200	6,600	880	9.5-12.5
Mare, lactating[2]																					
1st month	18.0	10.1	1,131	90	67	58	13	15	56	94	153	763	3.1	3.1	610	1,220	3.1	59,850	9,450	760	13.5-18.0
2nd month	19.8	10.3	1,091	96	60	51	12	15	56	94	163	813	3.3	3.3	650	1,300	3.3	64,600	10,200	810	15.0-19.0
3rd month	19.2	9.6	1,030	94	59	50	12	15	56	91	163	813	3.3	3.3	650	1,300	3.3	64,600	10,200	810	15.0-19.0
4th month	17.4	9.1	844	88	48	41	11	14	55	79	153	763	3.1	3.1	610	1,220	3.1	59,850	9,450	760	13.5-18.0
5th month	13.2	7.9	629	75	43	36	11	14	55	78	138	688	2.8	2.8	550	1,100	2.8	51,300	8,100	690	12.5-15.0
6th month	12.0	7.6	603	71	41	34	10	13	54	77	118	588	2.4	2.4	470	940	2.4	44,650	7,050	590	10.5-13.0

Columns UFC through Vit. E (IU): Daily nutrients allowances.

[1] Bodyweight 24 h after a normal foaling.

[2] The lowest values are for diets high in concentrates, the highest are to maximise forage consumption.

[3] An additional intake of 0.7 UFC and 35 g MADC is recommended for fillies bred at 3 years.

[4] Mares for recreational purposes may be fed at 90% of their energy requirements if their body condition score at the 6th month of gestation is 3 or more.

Table 3.10. Recommended daily nutrient allowances and intake allowances for draft horse mares with an adult bodyweight of **700 kg**.[1]

Physiological state		Daily nutrients allowances																				Dry matter intake[4] (kg)
		UFC		MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (IU)	Vit. D (IU)	Vit. E (IU)	
		Limited (80%)[2]	Nor mal (100%)[3]																			
Mare, dry or in early gestation		4.1	5.1	381	35	28	20	11	14	56	42	100	500	2.0	2.0	400	800	2.0	32.500	4,000	600	9.0-11.0
Mare, pregnant[5]																						
0-5 months		4.1	5.1	381	35	28	20	11	14	56	42	100	500	2.0	2.0	400	800	2.0	32,500	4,000	600	9.0-11.0
6th month		4.4	5.5	469	43	34	26	11	15	56	43	103	513	2.1	2.1	410	820	2.1	42,000	6,200	820	9.0-11.5
7th month		4.7	5.9	472	43	38	28	11	15	56	43	103	513	2.1	2.1	410	820	2.1	42,000	6,200	820	9.0-11.5
8th month		4.9	6.2	500	46	41	30	11	15	56	43	105	525	2.1	2.1	420	840	2.1	43,100	6,300	840	9.5-11.5
9th month		5.2	6.5	548	50	47	36	11	15	56	44	110	550	2.2	2.2	440	880	2.2	45,100	6,600	880	10.0-12.0
10th month		5.5	6.9	660	60	54	40	11	16	56	44	115	575	2.3	2.3	460	920	2.3	47,200	6,900	920	10.0-13.0
11th month		5.7	7.1	709	65	58	45	11	16	56	44	120	600	2.4	2.4	480	960	2.4	49,200	7,200	960	10.5-13.5
Mare, lactating[5]	Kg milk/d																					
1st month	21.0	11.3	13.6	1,305	104	78	68	15	18	66	109	185	925	3.7	3.7	740	1,480	3.7	71,250	11,250	925	16.0-21.0
2nd month	23.1	11.5	13.8	1,259	111	70	59	14	18	66	109	195	975	3.9	3.9	780	1,560	3.9	74,100	11,700	975	17.0-22.0
3rd month	22.4	10.7	12.8	1,187	109	68	58	14	18	66	106	185	925	3.7	3.7	740	1,480	3.7	71,250	11,250	925	16.0-21.0
4th month	20.3	10.1	12.1	970	92	56	48	13	16	64	92	173	863	3.5	3.5	690	1,380	3.5	65,550	10,350	865	14.5-20.0
5th month	15.4	8.7	10.4	720	86	50	42	12	16	64	91	153	763	3.1	3.1	610	1,220	3.1	57,950	9,150	765	13.5-17.0
6th month	14.0	8.3	10.0	689	81	48	40	12	16	64	90	153	663	2.7	2.7	530	1,060	2.7	50,350	7,950	685	11.5-15.0

[1] Bodyweight 24 h after a normal foaling.

[2] When body condition score at the start of winter is 3.5.

[3] When the body condition score at the start of winter is 3.0.

[4] The lowest values are for diets high in concentrates, the highest are to maximise forage consumption.

[5] An additional intake of 0.7 UFC and 35 g MADC is recommended for fillies bred at 3 years.

Table 3.11. Recommended daily nutrient allowances and intake allowances for draft horse mares with an adult bodyweight of **800 kg**.[1]

Physiological state	kg milk/d	UFC Limited (80%)[2]	UFC Nor mal (100%)[3]	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (IU)	Vit. D (IU)	Vit. E (IU)	Dry matter intake[4] (kg)
Mare, dry or in early gestation		4.5	5.6	421	38	32	22	12	16	64	48	105	525	2.1	2.1	420	840	2,1	34,100	4,200	630	9.5-11.5
Mare, pregnant[5]																						
0-5 months		4.5	5.6	421	38	32	23	12	16	64	48	105	525	2.1	2.1	420	840	2,1	34,100	4,200	630	9.5-11.5
6th month		4.9	6.1	521	47	39	29	12	17	64	49	108	538	2.2	2.2	430	860	2,2	45,200	6,500	860	9.5-12.0
7th month		5.2	6.5	525	48	43	32	12	17	64	49	108	538	2.2	2.2	430	860	2,2	45,200	6,500	860	9.5-12.0
8th month		5.4	6.8	557	51	47	34	12	17	64	49	110	550	2.2	2.2	440	880	2,2	46,200	6,600	880	10.0-12.0
9th month		5.8	7.2	612	56	54	41	13	17	64	50	115	575	2.3	2.3	460	920	2,3	48,300	6,900	920	10.5-12.5
10th month		6.1	7.6	739	67	61	46	13	18	64	50	120	600	2.4	2.4	480	960	2,4	50,400	7,200	960	10.5-13.5
11th month		6.3	7.8	780	72	66	51	13	18	64	50	125	625	2.5	2.5	500	1,000	2,5	52,500	7,500	1,000	11.0-14.0
Mare, lactating[5]																						
1st month	24.0	12.6	13.9	1,477	117	90	78	17	20	75	125	205	1,025	4.1	4.1	820	1,640	4,1	77,900	12,300	1,025	17.0-24.0
2nd month	26.4	12.9	14.2	1,424	125	80	68	16	20	75	125	215	1,075	4.3	4.3	860	1,720	4,3	81,700	12,900	1,075	18.0-25.0
3rd month	25.6	12.2	13.4	1,343	123	78	67	16	20	75	122	205	1,025	4.1	4.1	820	1,640	4.1	77,900	12,300	1,025	17.0-24.0
4th month	23.2	11.3	12.4	1,094	115	65	56	15	19	74	106	193	963	3.9	3.9	770	1,540	3,9	73,150	11,550	965	15.5-23.0
5th month	17.6	9.7	10.6	808	96	57	48	14	18	73	104	173	863	3.5	3.5	690	1,380	3,5	65,550	10,350	865	14.5-20.0
6th month	16.0	9.3	10.2	773	91	54	45	14	18	73	102	148	738	3.0	3.0	590	1,180	3,0	56,050	8,850	770	12.5-17.0

[1] Bodyweight 24 h after a normal foaling.

[2] When body condition score at the start of winter is 3.5.

[3] When the body condition score at the start of winter is 3.0.

[4] The lowest values are for diets high in concentrates, the highest are to maximise forage consumption.

[5] An additional intake of 0.7 UFC and 35 g MADC is recommended for fillies bred at 3 years.

the period where nutritional requirements are maximized (Figure 3.10). Foals are weaned at the age of 5-6 months. The goal is to consistently maintain the mare in good body condition throughout the cycle: a body condition score of 3.5. Both winter and summer feeding are important in reaching this objective. During the summer and the hottest hours mare and foal will usually be brought indoor where she can easily be given supplemental feed. The interval between two foalings will normally be 1 or 2 years depending on a successful pregnancy occurring on the 1st or second ovarian cycle in order to maintain an early birth date.

As a practical measure the mare will always be well fed since the owner will reduce risk even if it is costly (Tables 3.6 and 3.7). In winter the mare is fed high quality hay (Chapter 16), complemented with a concentrate feed supplement: 1.5 to 3.0 kg at the end of gestation and in early lactation depending on body condition which should never be excessive (optimal score is 3.5).

3.4.1.2 Competitive sports

Foaling occurs at the end of winter or early spring as the young horses enter competition at 4 years of age (Figure 3.11). Foals are weaned at the age of 6 months. Since gestation ends at the end of winter lactation takes place almost exclusively on pasture. Body condition may vary slightly during the cycle (score of 3.0 to 3.5), but it is dependent on feeding level at the end of winter and throughout the summer, as is the foaling interval. In winter the mare is fed good quality forage (Chapter 16), complemented with a concentrate feed supplement: 1.0 to 2.0 kg at the end of gestation.

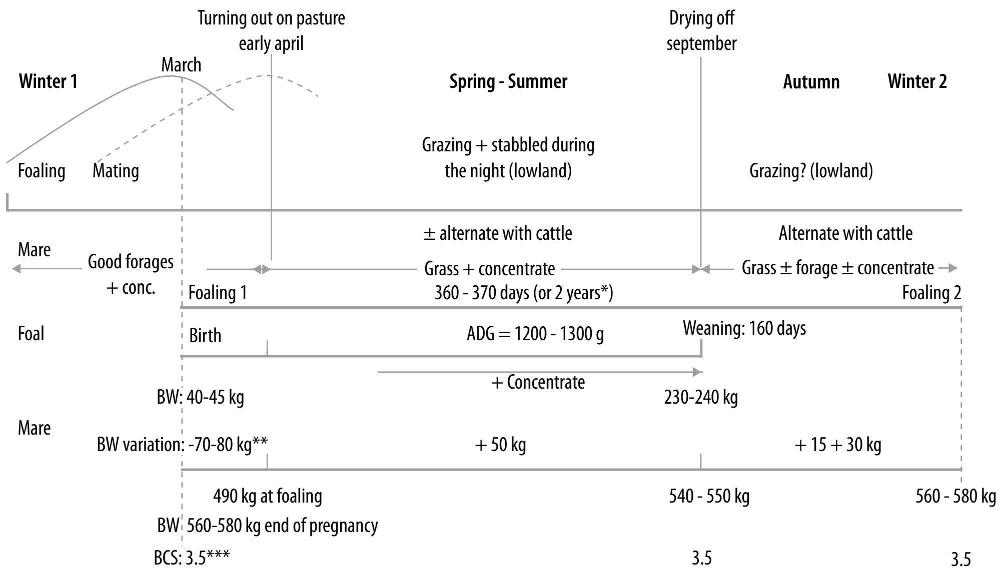

Figure 3.10. Annual management cycle of the racing breed mare (BW: 500 kg). BW = bodyweight; ADG = average daily gain; BCS = body condition score. * Relies on the successfulness of fertilisation to weaning the foal in early September, then to training at 15 months of age. ** Bodyweight loss corresponding to bodyweight of the foetus + digesta content. *** INRA/HN/IE (1997), Method to predicting body condition (scale 0 to 5).

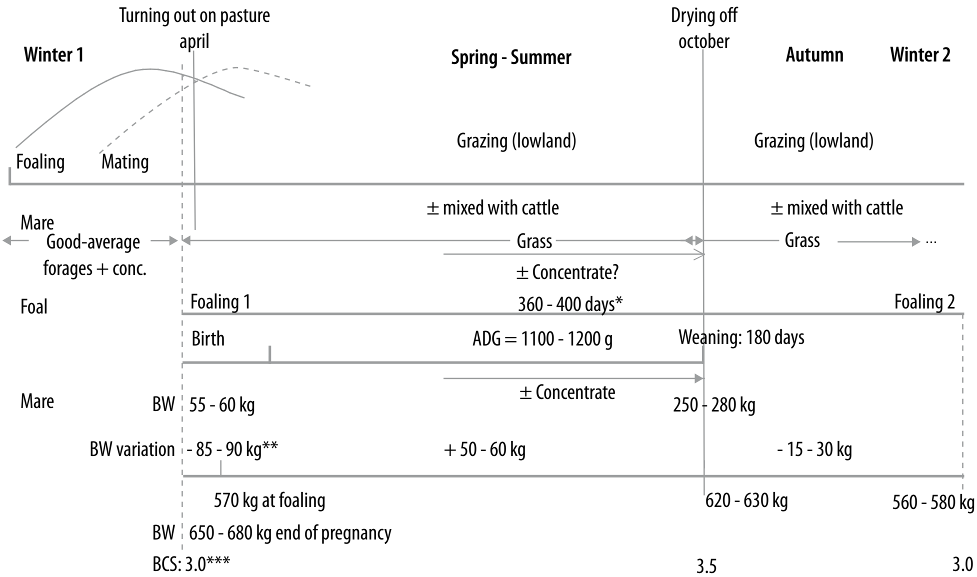

Figure 3.11. Annual management cycle of the competitive sport mare (BW: 550 kg). BW = bodyweight; ADG = average daily gain; BCS = body condition score. * Relies on the successfulness of fertilisation to weaning the foal in early September, then to training at 15 months of age. ** Bodyweight loss corresponding to bodyweight of the foetus + digesta content. *** INRA/HN/IE (1997), Method to predicting body condition (scale 0 to 5).

The recommended levels of nutrient intake are designed to meet nutritional requirements of mares destined to produce equine athletes (Tables 3.6 to 3.9).

3.4.1.3 Recreation

Foaling most often takes place after mares go to pasture since young horse normally enter training quite late at 3-4 years of age (Figure 3.12). Gestation and lactation take place, respectively, in winter and on grass. Foals are weaned at 6-7 months depending on pasture conditions in the fall. Body condition can vary considerably: scores of 2.5 to 3.5, since the pregnant mare's feeding conditions can be limited in winter and relatively abundant in summer while lactating. However, optimal body condition (score of 3.5) must certainly be attained in the fall in order to maintain a 12 month interval between foalings.

The recommended level of nutrient and feed intake may be limited to 90% of energy requirements during the winter gestation period of condition that the mobilisation of body reserves remains moderate: minimum score of 2.5-2.75 at foaling. The actual level of feed intake normally available on pasture must be above normal nutritional requirements (Tables 3.6 to 3.8) to rapidly attain a body condition score of 3.0 at the end of the first month of lactation and 3.5 at drying off.

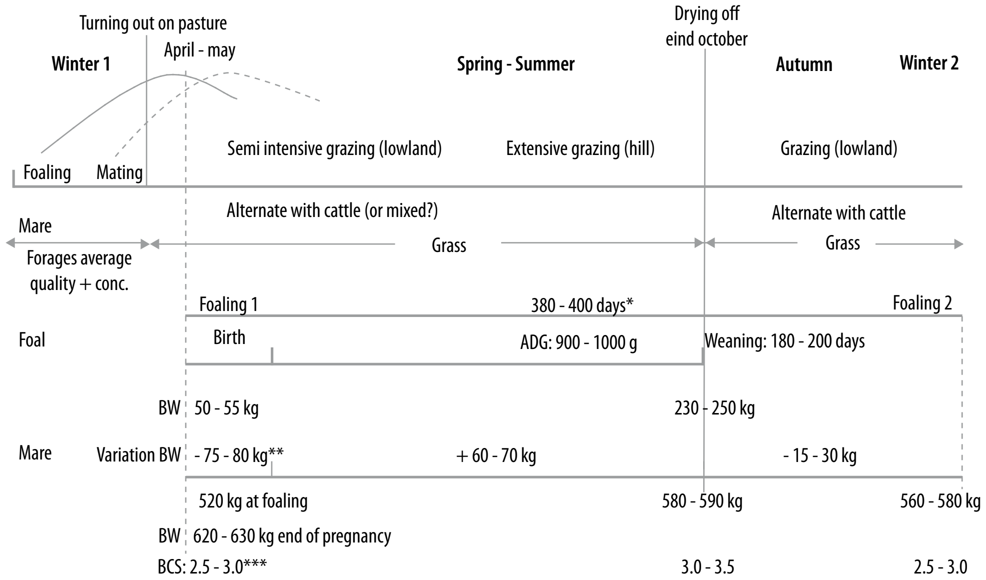

Figure 3.12. Annual management cycle of mares of the recreational segment (BW: 500 kg). BW = bodyweight; ADG = average daily gain; BCS = body condition score. * Relies on the successfulness of fertilisation to weaning the foal in early September, then to training at 15 months of age. ** Bodyweight loss corresponding to bodyweight of the foetus + digesta content. *** INRA/HN/IE (1997), Method to predicting body condition (scale 0 to 5).

In practical situations, in winter, the mares are fed average quality hays (Chapter 16), supplemented with a minimum quantity of concentrate feed: 1 to 2 kg at the end of gestation and in early lactation respectively, depending on the mare's body condition and pasture quality after foaling.

3.4.1.4 Draft mares destined to produce weanlings for fattening

The mares foal after going to pasture on farms only a few weeks before the trek to the high pastures where they are most often managed on the hills or mountains (Figure 3.13). Foals are weaned at 7-8 months at a weight of 330 to 350 kg depending on pasture conditions on the farm. Body condition varies significantly with scores ranging from 2.0 to 3.5 since the mares are underfed in winter (like beef cows). Body reserves are recovered on summer pastures, particularly soon after being put on pasture on the farm when it is fresh and abundant in early spring. Mares are bred soon after foaling to maintain a 12 month interval between foalings.

The recommended level of nutrient and feed intake can be limited to 80% of energy requirements during the winter gestation period, which can result in a body condition score of 2.5 at foaling. The level of feed intake at foaling must be much above normal nutrient requirements (Tables 3.10 and 3.11) in order that a score of 3.5 may be obtained by the time the mares finish lactating. This is possible if high quality pasture is available on the farm for the mares before they leave for mountain pastures where body condition will improve from 3.0 in the first month of lactation to 3.5 when lactation ends.

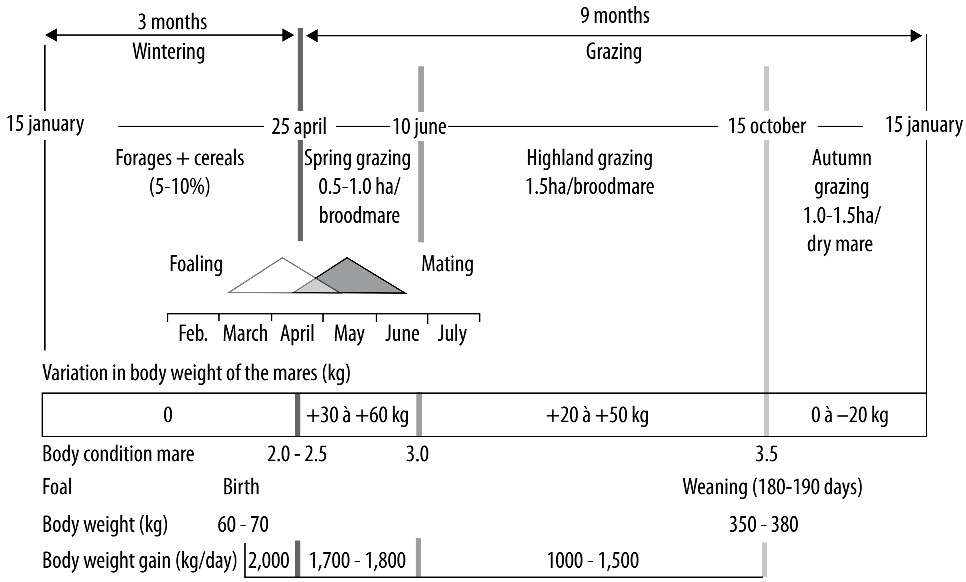

Figure 3.13. Annual management plan for draft broodmares (BW: 700 kg).

Draft mares are often managed entirely outdoor. Under such conditions a high feeding level must be maintained (Tables 3.10 and 3.11) and energy intake increased by 20% if winter temperatures are below -10 °C. Normally this increase in energy intake can be accomplished by increasing the quantity of forage available.

Under practical conditions mares are fed average to mediocre hay during the winter (Chapter 16). However, it is necessary to provide a minimum quantity of supplemental concentrate feed. About 1 kg is recommended at the end of gestation increasing to 2 kg in early lactation if foaling is early and depending on body condition and pasture conditions at foaling.

3.4.2 Intakes of protein, minerals, trace elements and vitamins

Nutritional requirements always dictate recommended intakes regardless of type of production (Tables 3.6 to 3.11). Effects of deficiency of these nutrients are not well known. Intakes of minerals and trace elements must be checked after formulating the diet using Table 2.1 in Chapter 2 and following the calculation techniques presented in Chapter 13.

3.4.3 Efficiency of reproduction

Nutritional effects can contribute to better control of reproduction in three areas:

- seasonality of ovarian activity;
- ovarian activity and ovulation;
- postpartum ovarian activity.

3.4.3.1 Seasonality of ovarian activity

Ovarian activity is advanced in winter when the duration of the period of inactivity is reduced. This occurs when the mare is well fed in the fall and early winter, or when the mare is in good body condition (scores of 3 to 3.5) in early winter.

Supplementation of the mare in order for her to have proper body condition (score ≥3) added to a lengthened photoperiod in early winter through the use of artificial lighting has an additive effect in advancing ovarian activity in early winter. Supplementation affects both energy supply and the quality of protein provided.

3.4.3.2 Ovarian activity and ovulation

Supplementation of the mare during winter aids in advancing the date of ovulation and even more if the mare is in less than ideal body condition (score <3). Giving the mare access to abundant, high quality pasture and the resulting weight gain also contributes to advancing the date of first ovulation.

3.4.3.3 Postpartum ovarian activity and fertility

In lactating mares, under nourished in energy during gestation and early lactation, with inadequate body condition (score <2.5), the number of cycles to become pregnant increases, fertility decreases and embryonic mortality increases.

The lactating mare with a body condition of 2.5 due to moderate energy restriction during gestation is not delayed in her first oestrus cycle provided she is fed to meet lactation requirements. However, fertility of this first cycle may be affected if nutrient intake is not sufficient to permit rapid return to a body condition score of 3.0.

3.4.3.4 Regaining body condition

The amount of additional feed, especially energy, and the duration of feeding to regain a minimal body condition of 3.0 during the postpartum period depends on the initial condition and the time available. It requires 30 to 90 days and an intake of 115 to 160% of maintenance depending on the interval under consideration in order for the mare to recover 0.25 to 0.75 points of condition (Chapter 2, Tables 2.2 and 2.5).

3.4.4 Fillies in year of first foaling

Age of puberty is 12 months on average in France for fillies born in May when feed intakes and the corresponding growth rates are maximised (Chapter 5, Tables 5.8 to 5.10, 5.16 and 5.17). It is 23 months for fillies born at a similar time but fed moderately with a corresponding moderate growth rate.

From a practical point of view there is no interest in having puberty occur at 12 months since the recommended age for fillies entering reproduction is 3 years for racing, competitive sport, recreation and draft breeds.

For fillies bred at 3 years, the recommended feed intakes are indicated as follows:

- In Tables 3.6 to 3.9 for light horse breeds: normal levels of energy and protein intake to which is added supplementary feed to ensure final growth is completed. This is indicated in table footnotes.
- In Tables 3.10 and 3.11 for draft breeds to which is added supplementary feed to ensure final growth is completed. This is indicated in Table footnotes.

The possibility of breeding 2-year-old fillies of the draft breeds has not been used as from animal management and economic standpoints it is risky. The difficulties in reproduction, obtaining sufficient growth to reach normal adult weight, and higher turnover rate at 4 years of age all argue against breeding this early.

3.4.5 Mares managed in groups

Draft mares are often managed in groups in the open air all year in winter feeding areas. A minimum stall system can permit mares to be individually fed concentrate feed if group management is causing difficulty. However, forage feeding, which represents 90% of the diet will remain on a group basis.

Two sub-periods are established for mares in the right body condition (score = 3) and in foal, 2 months before going on pasture where an average diet corresponding to the average physiological state of the herd is fed. From the time of entry to the wintering area until the first half of have foaled the diet should correspond to the arithmetic mean of intake recommended for mares in the 11th month of gestation and mare in the 1st month of lactation (limited level, Tables 3.10 and 3.11).

Example 3.1. 700 kg mares in good condition, average intake per mare.

Recommended energy and protein intakes:

11th month of gestation (limited level) = 5.7 UFC   709 g MADC

1st month of lactation (limited level) = 11.3 UFC   1,305 g MADC

Therefore $\frac{5.7 + 11.3}{2} = 8.5$ UFC $\frac{709 + 1{,}305}{2} = 1{,}007$ g MADC

From this time until going to pasture the diet should correspond to recommended intakes for the 1st month of lactation (Tables 3.10 and 3.11).

Example 3.2. 700 kg mare in good condition.

Therefore: 13.6 UFC and 1,305 g MADC

3.5 Pasture

The efficiency of reproduction and success of lactation in developing a foal to the appropriate weight for age depends on the mare's ability to ingest sufficient pasture forage just as she has at the trough with preserved winter forage. It has also been established, based on observations of winter feeding behaviour, that the mare fed free choice, three different green forages representing three stages of first cut hay can easily meet her energy requirements. Physiological state has no effect except when the forage is in the flowering stage and the mare is lactating and slightly in late pregnancy (Figure 3.14).

3.5.1 Meeting requirements from pasture

Racing breeds mares that are usually situated in humid growing zones where grass production is very high during the second part of lactation. Requirements can largely be met either from grass alone if quantities suffice, or by grass supplemented with limited amount of concentrate (maximum 2.0 kg/d) in the feed trough since these mares are usually stabled at the end of the afternoon until morning (Figure 3.15A). The mare will easily maintain body condition in this management system (Figure 3.10).

Mares of the competitive sport horse breeds in the moderately humid zones will most often meet requirements from forage. Exceptions are at the start of lactation if grass production is limited by extended winter weather and late grass growth, or by a wet spring which delays access to pasture areas (Figure 3.15B). At the end of lactation the mare will easily gain weight and a satisfactory body condition since, under good grazing conditions, she will gain in spring or summer and/or fall after an unfavourable early spring or even a moderate summer drought (Figure 3.11).

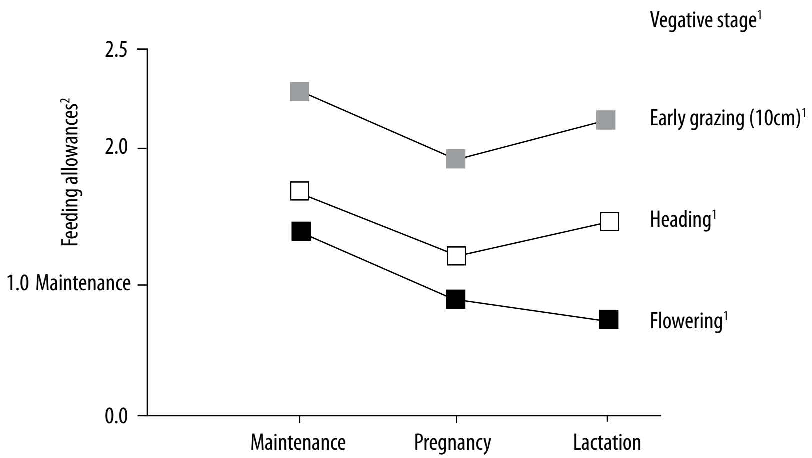

Figure 3.14. Energy balance of the mare according to vegetative stage of the pastured forage during the first cycle of growth of meadow grass (adapted from Theriez *et al.*, 1994). [1] Grass harvested and fed at trough. [2] Feeding allowances expressed as a multiple of maintenance requirement.

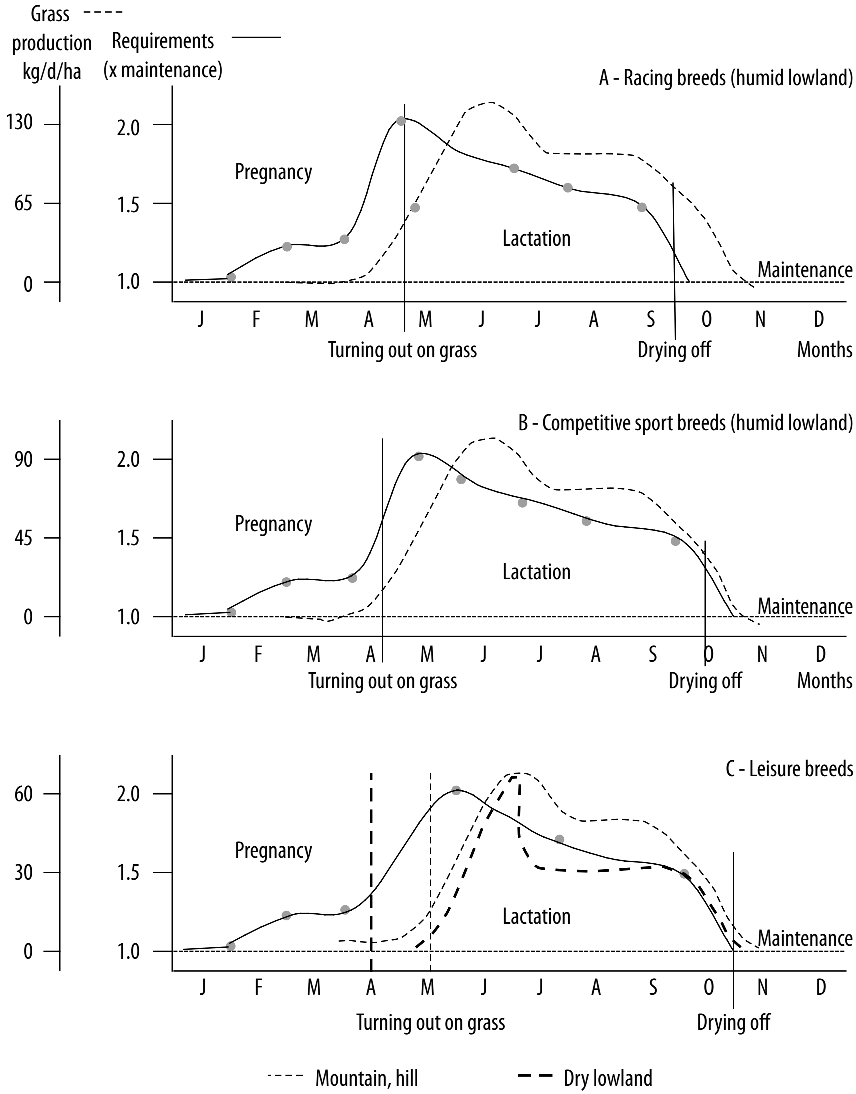

Figure 3.15. Variation in the mare's nutritional requirements and forage production throughout the year: (A) racing breeds, (B) sport horse breeds; (C) recreation and draft breeds.

Mares of the recreational and draft horse types managed in hilly or mountainous areas that may be wet or dry in summer are very dependent on the quality of grass available in spring and fall in achieving an optimal body condition at the end of lactation and becoming pregnant early in the postpartum period. Forage quality in spring and fall is normally above the mare's requirements as opposed to summer at least in the dry zones (Figure 3.15C). An area of abundant, good quality grass must be available when mares are put to pasture and in the fall to ensure the sustainability of the system. Management of body reserves is very important (Figures 3.12 and 3.13).

3.5.2 Mare supplementation

In practice, nursing mares of race or sport breeds dedicated to athlete horse production are often supplemented while on pasture with compound feeds or farm concentrates. Recent data obtained by INRA and IFCE showed that lactating mares meet their energy requirements without concentrate supplementation while grazing free choice fertilised grassland pastures. Variation of bodyweight and body condition are not significantly different between non-supplemented and supplemented groups. Growth of the foals is good and similar between the two groups (Table 3.12). These results support the previous observations made by INRA in lactating mares fed free choice medium to good hay-based diets supplemented or not with concentrates. Lactating mares can adjust intake while they are fed forage-based diets to meet energy requirements. However, mares, that are not supplemented at grazing, no longer meet their requirements when daily herbage allowances fall below 66 g DM/ kg BW/day, i.e 39 kg DM/day/mare (Collas *et al.*, 2014b).

While on pasture mares need a mineral supplement containing minerals and trace elements regardless of breed or type of pasture. Pasture contents of minerals and trace elements, especially calcium and/or phosphorus, copper and zinc are inadequate to meet requirements (Chapter 16). These minerals are also not present in the correct ratios according to nutritional principles (Chapter 1) and the rules of diet formulation (Chapter 13). With racing and competitive sport breeds supplementation takes place in the feed bucket in the form of compound feed since these mares are in box stalls at night.

Table 3.12. Effect of energy supplementation on voluntary intake and performance in light nursing mares rotationally grazed fertilised grassland pasture (adapted from Collas *et al.*, 2014a).

	Supplemented mare (n=8)	Non-supplemented mares (n=8)
Months of lactation	1.5-4th	1.5-4th
Duration (days)	90	90
Grass DMI: kgDM/al/d	13.5	15.5
Barley DMI: kgDM/al/d[1,2]	2.5	0.3
Total DMI: kgDM/al/d	16.0	15.8
NE intake: Mcal/al/d	26.4	24.4
Mare BW (kg)		
initial	590	595
final	607	616
BCS		
initial	2.9	3.3
final	3.6	3.6
Foal BW (kg)		
initial	106	89
final	199	180

[1] Included mineral supplement.

[2] Included marker to determine dry matter intake (plastic balls in order to individualise faeces at pasture for herbage intake measurements).

DM = dry matter; DMI = dry matter intake; NE = net energy (INRA system: Chapter 1); MADC = protein value (INRA system: Chapter 1); BW = bodyweight; BCS = body condition score (INRA scoring scale: 0 to 5; Chapter 2).

With draft mares and those for recreational purposes supplementation is provided by the use of mineralised salt blocks set out in pastures. However, the level of consumption should be monitored.

3.6 Prevention of nutritional problems

3.6.1 Nutritional balance

The nutritional principals to maintain in balance in order to prevent major problems in mares are relatively well understood (Chapters 1 and 2). They involve the following: kg DM/100 kg BW; g MADC/UFC; Ca:P; Zn:Cu; Vitamin A:D.

3.6.2 Problems of mineral metabolism

The hypocalcaemia (milk fever) problem prevalent in dairy cows is relatively rare in mares. In contrast, symptoms of hypocalcemia probably secondary to hypomagnesemia have been described in lactating mares.

The conditions of hypocalcaemia and/or hyperphosphatemia during a period of rapid intestinal absorption of these elements are not normally encountered in pregnant or lactating mares. Bone catabolism is well controlled by calcitonin secreted from parathyroid cells and prevents excessive demineralisation of the skeleton.

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Chapter 4. The stallion

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More than 6,000 stallions (excluding the 1,145 pony stallions (Chapter 8)) are used for reproduction in France: 7% Thoroughbreds, 8% Standardbreds, 46% sport and recreation, and 39% draft. Thoroughbred stallions are exclusively used in hand matings (99.5% of mounts), while 88.1% of Standardbred matings are by artificial insemination immediately after semen collection. Sport and leisure stallions are used for artificial insemination (75.7% of matings) with refrigerated semen used on site or transported frozen semen. 43.2% of mares in draft breeds are pasture bred but 33.5 and 22.8% respectively are hand matings or artificial insemination using refrigerated semen.

The actual rations for stallions are based on practical observations. Stallions are legally regulated to stand for public breeding at 4 years of age. It is, therefore, essentially an adult animal since it has attained at least 90% of growth and development.

4.1 Characteristics of the reproduction cycle

4.1.1 Principal characteristics of stallion reproduction

Sperm production or spermatogenesis starts in the testicular parenchyma of the young at about 18 months of age. However the capacity of the parenchyma to produce spermatozoids increases until 3 years of age and the stallion only reaches full maturity at 4 to 5 years. This observation is related to hormone concentrations (gonadotropins: follicle stimulating hormone (FSH) and luteinizing hormone (LH); steroid hormones: testosterone and oestrogen) which reach adult values about 5 years of age (Amann, 1993).

There is a very important relationship between hormone concentrations and the quality of spermatogenesis, therefore, factors influencing hormone levels will have effects on production and quality of spermatozoids. Moreover, when transiting the male genital tract, sperm will be in contact with various secretions of the epididymis and accessory glands, which function also depends on hormone concentrations.

4.1.2 Factors influencing variation in stallion reproductive function

Two types of factors can affect the reproductive function of the stallion: the intrinsic (internal) and the extrinsic (external).

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4.1.2.1 Intrinsic (internal) factors

Age

Production of spermatozoids increases from puberty (18-24 months) to adult (5 years) (Dowsett and Knott, 1996). For most stallions production and quality of spermatozoids peaks about 5 years and diminishes after 15 years of age (Clement *et al*., 1991).

Breed

Various studies have shown that semen parameters vary among breeds. In France, data from heavy breeds and light breeds show significant variation in sperm concentration, ejaculate volume and sperm mobility (IFCE, 2014). Ejaculate volume is much greater in heavy breeds compared with light breeds, while concentration and mobility is reduced. Studies conducted in the United States on various breeds (Quarter Horse, Appaloosa, Paint Horse, etc.) have similarly shown significant variability in seminal characteristics (volume of ejaculate, sperm concentration and mobility) (Dowsett and Knott, 1996; Pickett, 1993).

4.1.2.2 Extrinsic/external factors

Season

Numerous authors have reported variations in semen characteristics over the course of the year (Johnson *et al*., 1991; Pickett *et al*., 1975, 1989). This analysis was very important as it determined stallion reproductive function with much greater efficiency. As opposed to what happens with mares reproductive function in stallions is much less influenced by season. However, some changes were observed in a full year study at INRA. This study showed that winter (as opposed to spring and summer) is associated with reduced sexual behaviour, lower volumes of ejaculate, greater sperm concentration, and reduced gamete mobility. Similarly hormone levels vary with the season with increased concentrations of various hormones involved in reproductive function in spring and summer (Magistrini *et al*., 1987).

Photoperiod and season

Few studies have focused on photostimulation of stallion reproductive function. Contrary to expectations, trials using light stimulation did not stimulate spermatozoa production (Thompson et al., 1977) despite increased circulating levels of LH and testosterone, and testicular size.

Diet

Few studies have been reported on stallion reproductive function (see the review of Ellis *et al*., 2006), particularly on semen quantitative and qualitative characteristics. Work carried by INRA and IFCE demonstrated that age at puberty is influenced by level of food intake, growth and development (Guillaume *et al*., 2006). Age at puberty of saddle breed stallions, assessed by plasma testosterone concentrations of 0.5 ng/ml (which corresponds to the threshold concentration in winter of adult stallions producing a normal ejaculate) is 17 and 25 months, respectively, in young stallions having received since birth intakes corresponding to 150 and 100% of INRA recommendations. Observed liveweight and size attained at puberty expressed in relative values corresponding to the adult stage appear to be key elements. Well-fed or restricted young stallions reach a weight that is 79 and 63% and a wither height representing 95 and 90% of mature, respectively.

There are no reported studies in adult stallions to evaluate the effect of the level of dietary energy and protein on the production of sperm. In other species: bull, ram, boar, restricting intake temporarily affects semen quality (Brown, 1994). It appears in bulls that, after the young are weaned, moderate energy intakes are more favourable than high intakes on the development of sexual organs and semen characteristics (sperm motility and percentage of abnormal cells). Young bulls are more susceptible than adults. In the young stallion supplementing diets with lysine and methionine at levels much above requirements (40 to 80%) had no significant effect on quantitative parameters (volume, concentration, number of spermatozoids in the ejaculate) or qualitative (number of abnormal spermatozoids) in semen according to a study conducted by IFCE and INRA (Trillaud-Geyl and Magistrini, unpublished data), contrary to results reported for rams and bulls.

Attention must be given to zinc in stallions as a deficiency may disturb spermatogenesis and sex organ development in other farm animals. Zinc is a component of metallo-enzymes which are involved in enzymatic reactions associated with metabolisms that are of major concern for gonads development (Smith and Akibamijo, 2000). Supplementation of stallion rations with polyunsaturated fatty acids (PUFA) has been studied, since PUFA may have a specific effect on the composition of spermatozoids plasma membrane. PUFA supplementation in the form of rice oil containing vitamin E improves the antioxidant capacity of semen and the quality of the spermatozoids membrane as well as their mobility (Arlas *et al.*, 2008). In contrast, omega-3 supplementation in the form of docosahexanoic acid (DHA, 22:6, n3) has contradictory effects on the quality and total number of sperm and their survivability after 24 or 48 hours a 4 °C after freezing – thawing (Elhordoy *et al.*, 2008).

L-carnitine is a micronutrient normally synthesised in the liver, the kidneys and the brain from 2 amino acids: lysine and methionine. L-carnitine has been detected in seminal plasma and spermatozoa and a role has been identified in cellular energy metabolism. Nevertheless, supplementation has had no beneficial effect in healthy stallions (Stradaioli *et al.*, 2004).

A deficiency in vitamin E as well as in selenium, two micronutrients said to have an antioxidant effect on fatty acids, reduces sperm motility and increases the number of abnormal spermatozoids in the boar. In stallions providing vitamin E in the diet improved the motility of sperm after 48 hours of preservation at 4 °C. However, no effect was observed at 24 of preservation or after freezing and thawing (Gee *et al.*, 2008). Vitamin A is involved in spermatogenesis. It has been shown that in the stallion as in the bull a deficiency will reduce the mobility and increase the number of abnormal sperm. In contrast an intake in vitamin A by the stallion above recommended amounts has no beneficial effect (Ralston *et al.*, 1986). To date no consistent effect of supplementation of vitamin C on the fertility of stallions have been found (Ralston *et al.*, 1988).

4.1.3 Conclusions

When evaluating the quantity and quality of semen in a stallion, using a spermogram, it is very important to consider innate factors (age, breed) as well as external factors, such as the season in which observation is made, as well as the quantitative intake levels and nutritional balance. In addition it is important to compare semen parameters of a stallion with those of a population of individuals of the same breed and of normal fertility measured in the same season. The analysis of these data will permit the choice of an appropriate mate for the stallion in question in connection with a rational feeding program.

4.1.4 Annual reproductive cycle

Stallions have an annual reproductive cycle or alternatively, a breeding period and a period of sexual quiescence each with duration of about 6 months, similar to the mare's reproductive cycle.

4.1.4.1 Sexual cycle of breeding and quiescence

In the temperate zone stallions are in sexual quiescence and active breeding during the months of August to January and February to July respectively. This cycle of stallion activity corresponds to the mare's ovarian activity. Stallions of the sport horse and trotter breeds have semen collected for artificial insemination at specific cooling/freezing centres during this period of sexual activity. A stallion undergoes an average of 3 collections per week with semen quality carefully monitored during this time.

4.1.4.2 Breeding systems

Hand mating

Thoroughbred stallions are uniquely hand mated (the stallion mounts the mare both of which are under control of handlers). Trotting stallions are collected for artificial insemination (AI), which may take place immediately after collection or be preserved for later use. A large majority of sport horse stallions (85%) are collected for artificial insemination of mares.

Free-range breeding

Draft horse stallions are used essentially uniquely in pasture breeding situations with herds of mares of varying numbers (5 to 20) in mountainous or hilly areas referred to as multiplication zones. Hand mating, with or without deferred artificial insemination, is practiced mainly by small breeders. In this situation the collected semen is refrigerated, then transported to the farms for artificial insemination.

Exercise

Racing and sport horse stallions are housed in box stalls and given more or less daily exercise in paddocks, on a long line or by riding, especially for those who have an active sporting career. Draft horse stallions are most often housed in paddocks.

4.2 Nutritional requirements and recommended nutrient allowances during the stallion's annual breeding cycle

4.2.1 Nutrient requirements

Sexual activity and corresponding requirements vary according to the seasonal reproduction cycle of the horse.

4.2.1.1 Sexually quiescent period

The maintenance requirements of the stallion are the same as the adult gelding plus 5% for draft breeds and from 15 to 20% respectively for sport horse breeds and racing breeds (Chapter 1, Table 1.1). If a stallion is housed in a box stall his total requirements are equal to the sum of maintenance requirements and light work, such as brief turnouts, longeing or riding (Chapter 6, Tables 6.12 to 6.16 and Chapter 8, Tables 8.1, 8.4 and 8.7).

If the stallion is housed in paddocks or is free to roam in pens, especially those of draft horse breeds, the maintenance requirements previously identified are increased by 10 or 20% respectively. Depending on the situation successive increases may be additive.

Example 4.1 A draft stallion open housed a normal situation in pens. Maintenance requirements are 100% + 5% + 15% = 120% of basic requirements, which are:

5.6 UFC +0.3 UFC + 0.9 UFC = 6.8 UFC (Table 4.5).

4.2.1.2 Breeding period

To the period of sexual quiescence must be added: the requirements corresponding to physical exertions of sexual activity and sperm production. These requirements are quite variable depending upon the type of breeding, the precoital activity (teasing), the duration of tumescence before mounting and the quantity of sperm ejaculated.

In pasture breeding the expenditures relative to numerous movements and to the number of coverings compared to successful mating are more important than for the stallion undergoing hand mating. The stallion expends much energy in collecting his herd, isolating a mare in heat, and in breeding. There are 3 to 4 mountings for each effective mating for a stallion accustomed this type of breeding, with extremes of 2 to 15 respectively at the end and beginning of the breeding season.

Generally the expenditures related to breeding in the adult stallion must be met by the recommended nutrient allowances for a work intensity of light to intense, depending on the use of the stallion and the daily number of matings. Finally, the stallion should not have a body condition score less than 2.5 (Chapter 2, Table 2.2) at the end of the breeding season.

4.2.1.3 The young stallion, a particular case

The 4-year old stallion will have a higher expenditure than the older stallion because he is still growing and to ensure an appropriate end of growth for the slower growing breeds. He also lacks breeding experience. The increase in requirements for the young stallion is partially compensated by the fact that he will breed fewer mares than a mature stallion. In contrast, the requirements of a 3-year-old draft breed stallion allowed to breed, especially at liberty, must be increased. The maintenance requirement is, therefore, increased by 10%.

4.2.2 Recommended allowances

Recommended total nutrient allowances (maintenance + production) for energy, protein, minerals, microminerals and vitamins are presented in Tables 4.1 to 4.6 for the sexually quiescent period (maintenance + exercise), and the breeding period (maintenance + breeding, and eventually exercise for the stallions housed in box stalls) for 4 categories of stallions. Information on ponies is reported in Chapter 8, Tables 8.1, 8.4 and 8.7.

These allowances include the increases indicated previously with the exception of the 3-year old draft stallion for which a daily supplement of 0.3 to 0.5 UFC related to his remaining growth is added to the recommendations. Light horse and draft breeds are characterised by their live weight. In Tables 4.1 to 4.6 four live weights are highlighted: 450, 500, 550 and 600 kg for light horse and two live weights for draft breeds: 800 and 900 kg.

Three breeding intensities are indicated as a function of number of daily matings and the type of mating and collection in artificial insemination (AI):

- Light: one mating every 2 days; hand mated or collection for AI in a breeding facility for a mature stallion or 3 or 4 year-old stallions.
- Medium: 1 mating per day: hand mated in a breeding facility hand mating or collected for AI, mature or 4-year-old stallions.
- Intense: 2 matings or more per day, hand mated or pasture breedings with mature stallions.

These nutrient allowances permit, on average, the stallions to retain their live weight and a constant body condition with a score of 3 (Chapter 2, Table 2.2) during the breeding season. Variations are possible because of breed, stallion temperament and the type of breeding.

Stallions that are thin by the end of the breeding season are returned to adequate condition between breeding seasons:

- Either in a first approximation by providing for 2 months a total nutrient allowances corresponding to the medium service or light service if the body condition score is equal to or below 2 to 2.5. This corresponds to a loss of bodyweight of about 10 to 5% during the breeding season.
- Or, more accurately, using the adjustment grid for nutrient allowances proposed in Chapter 2, Table 2.5.

Table 4.1. Recommended daily nutrient allowances and intake allowances for light horse stallions with adult bodyweight of **450 kg**.

Utilisation	Daily nutrients allowances																			Dry matter
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake [3] (kg)
Non breeding[1]	5.3	382	35	27	17	9	13	43	27	105	525	2.1	2.1	420	840	2.1	34,100	4,200	525	9.5-11.5
Breeding period: service[2]																				
Light	6.3	454	41	27	17	9	13	43	27	105	525	2.1	2.1	420	840	2.1	34,100	4,200	525	9.5-11.5
Moderate	6.9	497	45	32	19	10	17	50	31	115	575	2.3	2.3	460	920	2.3	43,100	6,900	920	10.5-12.5
Intense	7.7	554	51	36	26	14	23	60	36	115	575	2.3	2.3	460	920	2.3	43,100	6,900	920	10.5-12.5

[1] Includes 1 hour daily light exercise for stall-managed stallions.

[2] The data correspond to stall-managed stallions under natural mating conditions.

[3] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake. This dry matter intake accounts for the amount that is necessary to meet nutrient requirements (and the bedding straw that the stallion may consume when it is housed in a box stall).

Table 4.2. Recommended daily nutrient allowances and intake allowances for light horse stallions with adult bodyweight of **500 kg**.

Utilisation	Daily nutrients allowances																			Dry matter
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake [3] (kg)
Non breeding[1]	5.8	418	38	30	19	10	15	48	29	113	490	2.3	2.3	450	900	2.3	36,600	4,500	560	10.0-12.5
Breeding period: service[2]																				
Light	6.7	482	44	30	19	10	15	48	29	113	490	2.3	2.3	450	900	2.3	36,600	4,500	560	10.0-12.5
Moderate	7.6	547	50	35	21	12	18	56	33	123	510	2.6	2.6	510	1,020	2.6	47,800	7,700	1,020	11.0-13.5
Intense	8.5	612	56	40	29	15	26	67	39	123	510	2.6	2.6	510	1,020	2.6	47,800	7,700	1,020	11.0-13.5

[1] Includes 1 hour daily light exercise for stall-managed stallions.

[2] The data correspond to stall-managed stallions under natural mating conditions.

[3] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake. This dry matter intake accounts for the amount that is necessary to meet nutrient requirements (and the bedding straw that the stallion may consume when it is managed in a box stall).

Table 4.3. Recommended daily nutrient allowances and intake allowances for light horse stallions with adult bodyweight of **550 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake [3] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Non breeding[1]	6.3	454	41	33	21	11	16	53	33	120	600	2.4	2.4	480	960	2.4	39,000	4,800	600	10.5-13.5
Breeding period: service[2]																				
Light	7.3	526	48	33	21	11	16	53	33	120	600	2.4	2.4	480	960	2.4	39,000	4,800	600	10.5-13.5
Moderate	8.2	590	54	39	23	13	21	62	37	135	638	2.6	2.6	510	1,020	2.6	47,800	7,650	1,020	11.5-14.5
Intense	9.3	670	61	44	32	17	28	73	43	128	638	2.6	2.6	510	1,020	2.6	47,800	7,650	1,020	11.5-14.5

[1] Includes 1 hour daily light exercise for stall-managed stallions.

[2] The data correspond to stall-managed stallions under natural mating conditions.

[3] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake. This dry matter intake accounts for the amount that is necessary to meet nutrient requirements (and the bedding straw that the stallion may consume when it is managed in a box stall).

Table 4.4. Recommended daily nutrient allowances and intake allowances for light horse stallions with adult bodyweight of **600 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake [3] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Non breeding[1]	6.8	490	45	36	23	11	18	58	35	128	638	2.6	2.6	510	1,020	2.6	41,100	5,100	638	11.0-14.5
Breeding period: service[2]																				
Light	7.9	569	52	36	23	11	18	58	35	128	638	2.6	2.6	510	1,020	2.6	41,100	5,100	638	11.0-14.5
Moderate	8.9	641	58	42	25	14	23	67	40	138	688	2.8	2.8	550	1,100	2.8	51,600	8,300	1,100	12.0-15.5
Intense	10.0	720	66	48	35	18	31	80	47	138	688	2.8	2.8	550	1,100	2.8	51,600	8,300	1,100	12.0-15.5

[1] Includes 1 hour daily light exercise for stall-managed stallions.

[2] The data correspond to stall-managed stallions under natural mating conditions.

[3] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake. This dry matter intake accounts for the amount that is necessary to meet nutrient requirements (and the bedding straw that the stallion may consume when it is managed in a box stall).

Table 4.5. Recommended daily nutrient allowances and intake allowances for draft horse stallions with adult bodyweight of **800 kg**.

Utilisation	Daily nutrients allowances																						Dry matter
	UFC		MADC (g)		Lysine (g)		Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[4] (kg)
Non breeding[1]	5.9[2]	6.8[3]	413[2]	476[3]	38[2]	43[3]	35	25	13	19	76	44	130	650	2.6	2.6	520	1,040	2.6	42,300	5,200	650	11.5-14.5
Breeding period: service																							
Light	6.4[2]	7.6[3]	448[2]	532[3]	41[2]	48[3]	36	30	15	19	76	51	130	650	2.6	2.6	520	1,040	2.6	42,300	5,200	650	11.5-14.5
Moderate	6.9[2]	8.4[3]	483[2]	588[3]	44[2]	54[3]	43	34	18	30	90	58	143	713	2.9	2.9	570	1,140	2.9	53,400	8,600	1,140	12.5-16.0
Intense	7.9[2]	10.0[3]	553[2]	700[3]	50[2]	64[3]	50	36	24	41	106	69	143	713	2.9	2.9	570	1,140	2.9	53,400	8,600	1,140	12.5-16.0

[1] Includes 1 hour daily light exercise for stall-managed stallions.

[2] The data correspond to stall-managed stallions under natural mating conditions.

[3] The data correspond to stallions managed outdoors in natural, herd pasture-mating.

[4] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake. This dry matter intake accounts for the amount that is necessary to meet nutrient requirements (and the bedding straw that the stallion may consume when it is managed in a box stall).

Table 4.6. Recommended daily nutrient allowances and intake allowances for draft horse stallions with adult bodyweight of **900 kg**.

Utilisation	Daily intake																						Dry matter
	UFC		MADC (g)		Lysine (g)		Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[4] (kg)
Non breeding[1]	6.4[2]	7.4[3]	448[2]	518[3]	41[2]	47[3]	40	28	15	26	86	50	138	688	2.8	2.8	560	1,100	2.8	44,700	5,500	688	12.5-15.0
Breeding period: service																							
Light	6.9[2]	8.4[3]	483[2]	588[3]	44[2]	54[3]	40	34	17	26	86	58	138	688	2.8	2.8	560	1,100	2.8	44,700	5,500	688	12.5-15.0
Moderate	7.4[2]	9.4[3]	518[2]	658[3]	47[2]	60[3]	47	38	21	35	100	66	150	750	3.0	3.0	600	1,200	3.0	56,300	9,000	1,200	13.5-16.5
Intense	8.4[2]	10.4[3]	588[2]	728[3]	54[2]	66[3]	53	40	27	46	120	75	150	750	3.0	3.0	600	1,200	3.0	56,300	9,000	1,200	13.5-16.5

[1] Includes 1 hour daily light exercise for stall-managed stallions.

[2] The data correspond to stall-managed stallions under natural mating conditions.

[3] The data corresponds to stallions managed outdoors under natural herd mating conditions.

[4] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake. This dry matter intake accounts for the amount that is necessary to meet nutrient requirements (and the bedding straw that the stallion may consume when it is managed in a box stall).

4.3 Practical feeding

The diet must meet the nutritional needs of the stallion without being in excess. It may be harmful to the reproductive function of the stallion and his cardiovascular and locomotor structures to over feed whether it is young males before presentation for evaluation or mature stallions.

It is necessary to prepare for the upcoming breeding season by progressively increasing feed intake beginning in early January to allow at least 15 days between the beginning of breeding and the recommended increase in nutrient allowances.

Sport horse and trotter stallions, whose semen is collected for freezing and may be used outside of the period from February to July (the traditional breeding period), must be on a feeding program suited to their breeding activity.

4.3.1 Stallions housed in box stalls or in paddocks

This is the situation for most stallions, with the exception of draft stallions that are on pasture breeding programs and are normally housed in loose housing or on pasture in the breeding period. Stallions can be fed with diets based on dry forages: hay or silage or wilted silage, in both cases complemented with cereal grains and a vitamin-mineral feed supplement (VMFS) of the 7-12 type (7% P and 12% Ca) the composition of which is indicated in Chapter 13, Table 13.3, 50 g column. A complementary formulated concentrate feed may also be fed that is similar to that provided for mares which have the advantage of containing a VMFS. The amount of the concentrate feed in the diet ranges from 10 to 30% according to the level of service required, no breeding to intense service, body condition and certainly on the nutrient content of the base forage.

For stallions who will also be competing one must also consider the requirements related to work (Chapter 6, especially Figure 6.11 in which the requirements are added to those of breeding and semen collection for AI).

4.3.2 Stallions managed in the winter paddocks or on meadows

This situation concerns exclusively (or nearly) draft horse stallions pasture breeding in range lands or hilly area. During the breeding season and before going onto pasture the stallion on the range receives a diet based on meadow hay (the same quantity as a lactating mare of a similar size and 3 to 5 kg of a concentrate consisting of 50% oats and 50% of a commercial supplement. This supplement should have a composition similar to that provided for the mares or a mix of cereals similar to that fed to stallions housed in box stalls or tie stalls plus 50 g of a VMFS the composition of which is close to that indicated in Chapter 13, Table 13.3, column 50 g.

During the breeding season and after being at pasture the diet base is provided by the abundant, fresh, high quality spring grass. The stallion also needs a supplement of 2 to 3 kg of concentrate feed consisting of 50% oats and 50% of a complimentary compound supplement (mare feed). This supplementation is necessary since the stallion will spend less time grazing than will the mares.

During the non-breeding period grass will meet the needs of the stallion if it is abundant and of at least average quality throughout the summer. A trace mineralised salt block available in the pasture will be necessary to provide the required balance to the diet in minerals and microelements. If the quantity of grass becomes insufficient and/or the body condition of the stallion is poor it will be necessary to provide 2 to 3 kg per day good quality hay (first cut harvested when headed out) and 2 kg of barley or corn.

4.4 Prevention of nutritional problems

4.4.1 Nutritional balance

Stallions as all other horses should be fed according to recommended guidelines designed to meet their requirements. This will provide the essential nutritional balance established when nutrient requirements were evaluated. In normal situations particular supplementation is not necessary as is indicated at the beginning of this chapter.

4.4.2 Body condition and obesity

The stallion should, during the annual breeding cycle, have body condition scores as follows:

- *Sport and race horses.* An optimum score of 3 should be achieved and maintained throughout the annual cycle for natural mating or sperm collection under hand control. A score of 3.5 may be preferable for those stallions that are more difficult to maintain.
- *Draft breeds.* Body condition score should be monitored over the breeding season: from 3.5 at the beginning of the season and never dropping below 2.5 during the season. If body condition is lost the stallion must be managed in such a way as to restore the score to 3.5 during the non-breeding season.

The obese state is considered to be a score of 4 or more. There are only disadvantages to this state: muscle disorders, osteo-articular and possible digestive problems (Chapter 2).

Using the method described in Chapter 2 to estimate body condition is recommended. Body condition should be estimated monthly if possible coupled with a live weight measurement (empty stomach in the morning before a meal) to accurately adjust feed allocations according to continuous, objective criteria. Intake adjustments should be made using the most accurate technique: the chart proposed in Chapter 2, Table 2.5.

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Chapter 5. The growing horse

William Martin-Rosset, Catherine Trillaud-Geyl and Jacques Agabriel

France is a major European producer of horses for racing, sport and recreation. Annually 16 to 17,000 race-horse births are recorded (68 and 32% Trotters and Thoroughbreds, respectively), 19 to 20,000 births of foals in sport and leisure and 16 to 17,000 draft foal births.

The growth period for horses lasts from 3 to 5 years, accounting for 40 to 70% of productive life depending on genetic type (Thoroughbred, Trotter, Selle Francais, Anglo-Arab or Arab) and use (racing, sport or leisure). For producers and users of horses this represents a large management and financial investment that influences ultimate performance, longevity and profitability. This is a risk period, where nutritional requirements and balance must be met to prevent the onset of pathologies, particularly of osteo-articular origin.

5.1 Growth and development

5.1.1 Phenomena and their measurements

From birth to adulthood growth in horses is indicated by an increase in liveweight and body dimensions as a function of time. Development is the set of phenomena that guide the formation of the adult horse from the fertilised egg. During gestation the embryo evolves through various phases to become a foetus then, at parturition, a foal. This process continues through adult age, producing morphologic, anatomic and chemical modifications that result in psychic and sexual maturation. Development is measured by comparing weight, size or anatomical and chemical composition of a region or tissue at a given age to a reference element. This reference could be the value (weight, dimension, composition) of the region or tissue at the adult age or the value at the same age considering the entire organism.

5.1.2 Weight gain

At birth the foal has a liveweight representing 8 to 12% of its mother: that is about 15-35 kg for ponies (Chapter 8), 45-55 kg for light horses and 65-80 kg for draft horse breeds. During the first month the foal will double its birth-weight. At weaning at the age of 6-7 months foal weight will be 5 times its birth-weight. Its weight at this point will be 220-260 kg for light horses and 300-400 kg for draft horse breeds (that is about 45% of adult weight). Wither height will be about 80% of adult value. At one year of age weight will be about 65% of adult value and wither height about 88%. During its first year the foal will have achieved 50-60% of its mature bodyweight and about 70% of its final height. The weight of a foal at 2 years represents 75% of its adult liveweight which it finally reaches at 3.5 to 5 years depending on the breed (Figure 5.1).

Growth rate is measured by liveweight gain expressed as grams per day (g/d). Gain is very rapid during the first month of life: from 1,500 g/d (for light horse breeds) to 2,000 g/d (for draft breeds). It depends not only on the genetic potential of the foal but also on the mare's milk production up

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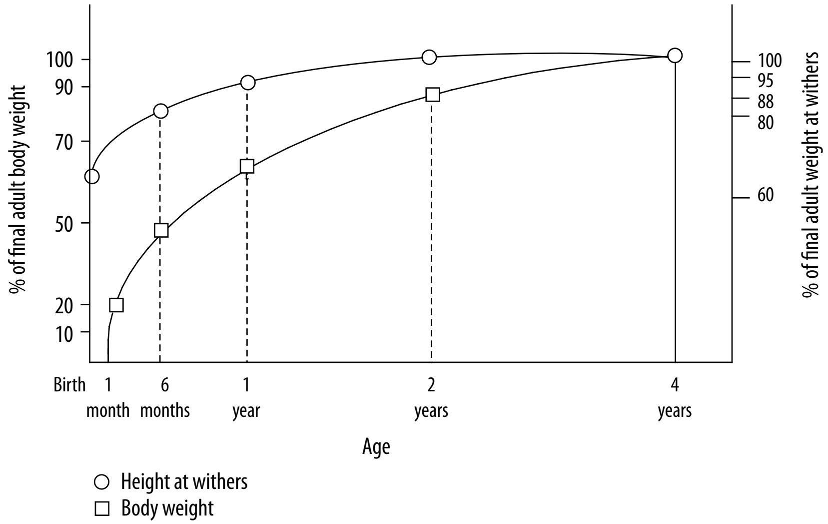

Figure 5.1. Liveweight and wither height of light horse breeds as a function of age.

to 3 months, the age when the foal starts to supplement its diet with significant amounts from other sources (pasture, concentrate feeds, hay). From birth to weaning foals have an average daily liveweight gain of 900 to 1000 grams for light horse breeds and from 1,300 to 1,600 for draft horse breeds. Between weaning and one year of age liveweight gain varies from 600 to 1,600 g/d depending on genetic makeup (light horse vs draft). Gain slows with age and is dependent upon management practices. After one year of age growth follows a slower pattern: on average 150 to 300 g/d until adult size is reached at about 3 to 4 years for race horses and 4 to 5 years in sport and leisure breeds.

5.1.3 Pattern of growth

Wither height in foals at birth is already approximately 60% of final adult height, while weight is only 10% of adult weight. The skeleton is already more developed than muscle or fat tissue. From birth to weaning wither height increases on average 5 cm per month in light horses. Between weaning and one year the average increase in height is about 2 cm per month in light breeds.

During the first year post-partum, the outline of the foal can be included in an upright rectangle since the wither height is about 88% of adult height, because the foal is tall but compact (Figure 5.2). The foal has completed nearly 70% of its growth in size. Between one and two years girth and chest width increases 65% while length increases to a lesser extent. The yearling may then be enclosed by a square. From 2 years to adult body length increases by 60% and the horse may then be outlined by a recumbent rectangle (Figure 5.2). Growth patterns are closely linked to liveweight, while the latter can be predicted with high precision from certain pattern parameters (Chapter 2).

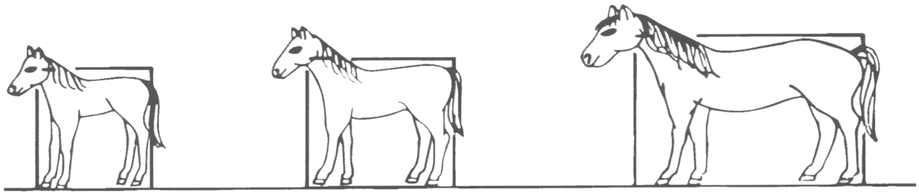

Figure 5.2. Growth patterns from birth (Martin-Rosset, 1983).

5.1.4 Tissue development

Weight change of body tissues (bone, muscle, adipose) has been described by INRA using the comparative slaughter method. Body development as a function of time is characterised by relative changes in the anatomical composition expressed by the weights of the different tissues. This development is described according to the classic allometric equation $y = ax^b$. In this equation b is the allometric coefficient, y = the weight of the tissue in relation to x which is the weight of the empty body (EBW = bodyweight minus the contents of the digestive tract, which can be very variable). If b is equal to 1 the tissue in question (y) is developing at the same rate as the empty body (x) or that it has the same relative growth rate. If b is greater than 1 the tissue in question is developing at a faster rate than the empty body and conversely if b is less than 1 (Figure 5.3).

The carcass (i.e. the collection of tissues: bone + muscles + fat or adipose depots) has an allometric coefficient of 1 which indicates that the carcass develops at the same rate as the entire body (carcass + organs, digestive tract, skin, etc.) between birth and 30 months. In contrast, the relative growth of the entire skeletal tissues (= total skeleton) is low: b=0.74 while that of muscle tissue and adipose tissue are respectively high and very high: b=1.13 and b=1.41. Therefore, the percentage of adipose tissue and muscle tissue in the carcass increases from 6 to 12% and 59 to 69%, respectively, while that of bone decreases considerably from 32 to 14%.

The development of skeletal tissue occurs very early compared to other tissues as its allometric coefficient is much less than 1. Adipose tissue has a much later development as its allometric coefficient is much greater than 1. Muscle tissue has an intermediate rate but its coefficient is also greater than 1 (Figure 5.3). These are important considerations in the evaluations of nutritional requirements with age. The same tissue in different anatomic regions may not develop at the same rate when compared to this tissue in the total body.

There is a very clear gradient of relative skeletal development as bones in the extremities develop earlier. The canon bone in particular develops very early in the direction of the barrel and vertebral column that are relatively late developing. Intermediate skeletal members have an average rate of development close to that of the entire skeleton. The relative growth of the different regions of the skeleton is the reason for the form outlined in Figure 5.4.

The relative growth of different adipose tissue depots in comparison with total adipose tissue is highly differentiated between birth and 30 months. It varies from 0.95 for intermuscular deposits

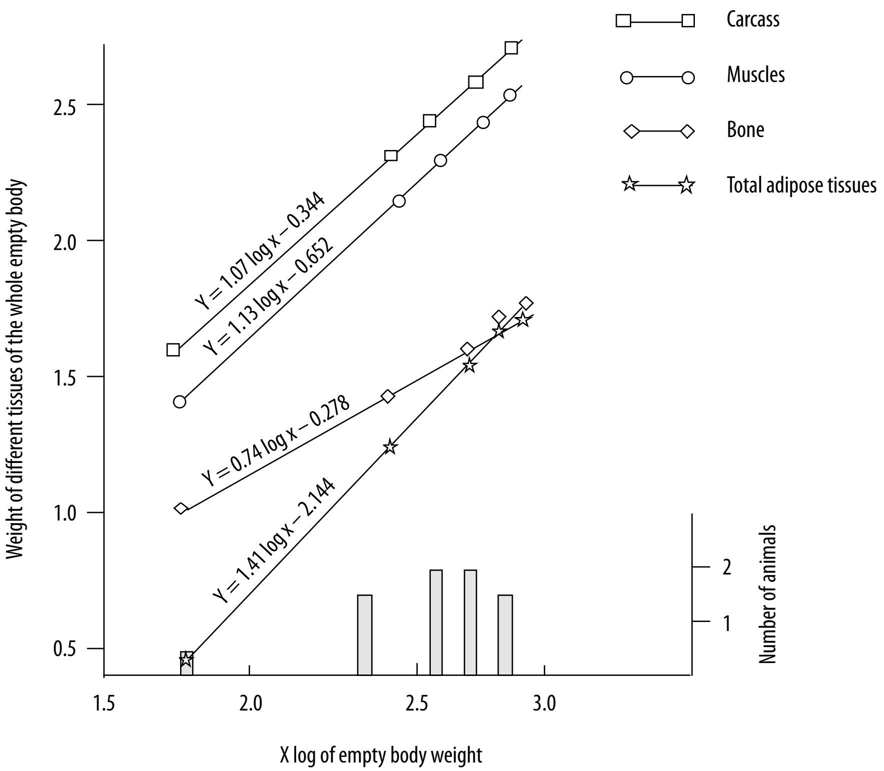

Figure 5.3. Tissue growth (y in kg) relative to empty bodyweight (x in kg) from birth to 30 months (Martin-Rosset *et al.*, 1983).

to 1.58 for internal thoracic or abdominal fat while subcutaneous fat has a relative rate of 1.14. These considerations are important for the estimation of body condition by the handling method (Chapter 2).

The relative growth of muscle tissue is also somewhat differentiated. It varies from 0.80 for the extremities to 1.04 for muscles of the back and thorax.

5.1.5 Consequences of variation in body composition with liveweight for the determination of nutritional requirements.

During growth the proportion of muscles that contributes to daily gain is relatively constant since the allometric coefficient is close to 1 while the skeletal contribution diminishes since its allometric coefficient is less than 1. In contrast, adipose tissue is the most variable element in the whole body as its relative growth is very high. This is the reason that composition of the gain varies during growth: the more the liveweight of the foal increases, the greater the proportion of adipose tissue in the gain. In correlation, the lipid content and thus the calorific value of the gain increases more and more.

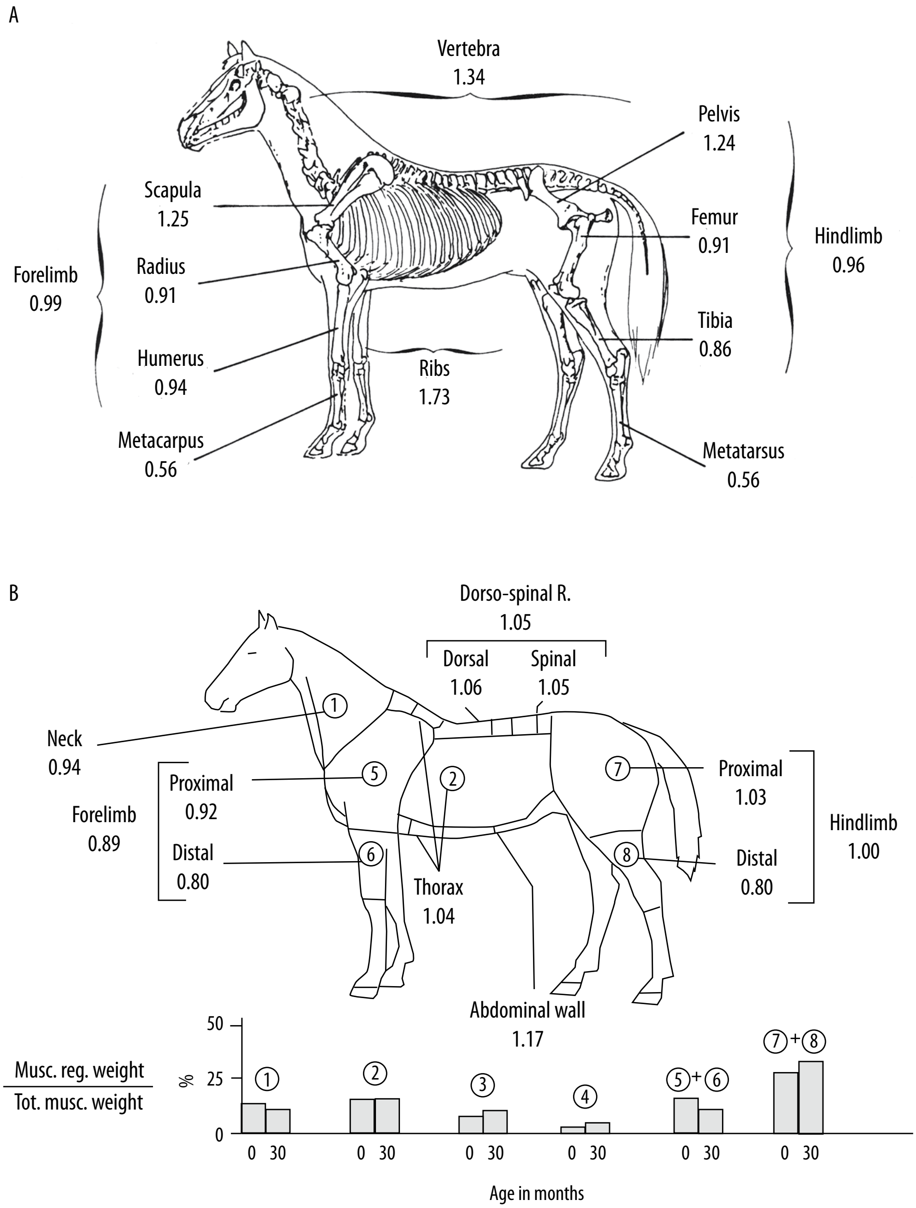

Figure 5.4. Relative growth of different regions of the skeleton (y in kg) in relation to the entire skeleton (x in kg) from birth to 30 months (Martin-Rosset *et al.*, 1983).

INRA has determined the average chemical composition (content of lipids, proteins and water) of the body mass at various ages from the anatomical composition of the experimental animals in order to describe relative tissue growth. From the results, the chemical composition of the gain in lipids, proteins, and water has been estimated in order to establish the net requirements of the growing horse (Figure 5.5A). The variation of the lipid content of the gain as a function of weight gain has also been established to take into account the growth rate in the evaluation of requirements (Figure 5.5B).

5.1.5.1 The special case of bone tissue

The skeleton is composed of bony tissue, conjugation cartilage, epiphyseal plate cartilage (during growth) and articular cartilage. Bone tissue is the site of bone modelling during growth phases as well as a remodelling in the adult (in fact modelling and remodelling coexist during growth but modelling is more important. This is the reason bone formation occurs in foals as in other species, while only remodelling occurs in adults). Bone tissue is produced during the modelling phase. Remodelling allows bone to play its role as a mineral reserve, notably of calcium, as well as permitting restructuring to strengthen mechanical properties.

Bone tissue is composed of connective tissue, an organic matrix and mineral substances. Connective tissue is made up of cells, and intercellular substance which has the characteristic of being calcified by mineral deposits on an organic matrix.

The organic matrix is composed of type I collagen fibres which constitute 90% of the framework of the defatted, dry bone. The remaining 10% consist of very varied components: glycoproteins (primarily osteonectin and sialprotein), phosphoproteins, phospholipids, proteins containing gamma-carboxy-glutamines (osteocalcin: bone gla protein and matrix gla protein) and proteoglycans.

The mineral component of bone tissue consists of a crystallised calcium phosphate in the form of hydroxyapatite in the interfibular spaces, along the collagen fibres and sometimes within the fibres. The mineral substance represents 50% of fresh weight of bone and 70% of dry bone (the adult skeleton contains 99 and 90% of the organism's calcium and phosphorus, respectively).

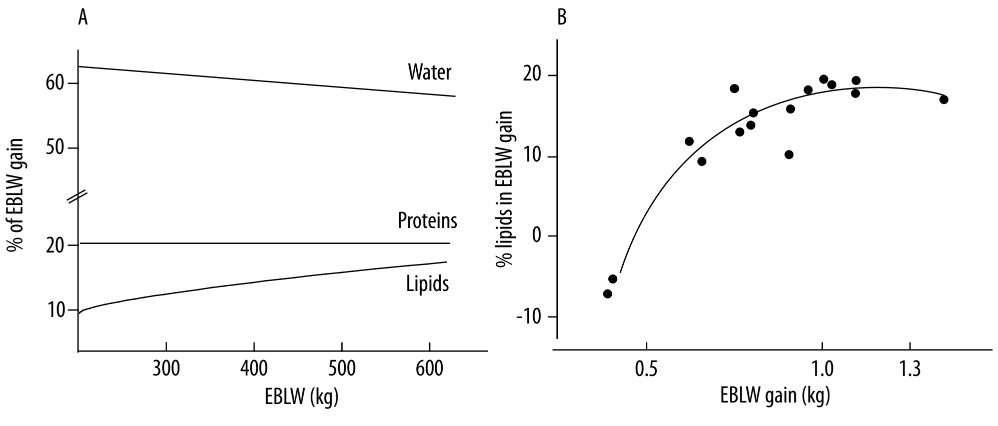

Figure 5.5. Evolution of the chemical composition of the empty body liveweight gain (EBLG) between 6 and 30 months. (A) Variation of the composition as a function of liveweight growth. (B) Variation of the lipid content as a function of empty bodyweight gain (example between 6 and 12 months. EBW = empty bodyweight (Agabriel *et al.*, 1984).

Bone has a special texture and architecture that change with age. Bone tissue in the young consists of non-lamellar, immature fibrous bone characterised by the anarchaic and disorganised disposition of collagen fibrils of the protein framework. In contrast bone in the adult is characterised by a lamellar (organised) texture which gives its mechanical strength.

The grouping and form of the lamina determine whether the bone is compact or cancellous. If we consider one bone (which will be used later as a reference when investigating mechanical properties) it consists of three parts:

- the shaft, compact bone widened at the centre by its medullary cavity filled with bone marrow;
- the epiphyses, cancellous bone the end of which is covered by articular cartilage;
- the metaphyses, situated under the growth plate are the site of endochondral ossification responsible for the elongation of the bones.

Ossification occurs in three stages (Figure 5.6). The primary ossification develops from the cartilaginous model of the fibrous bone. It takes place at the growth plate during the development of the diaphysis and epiphysis during the growth phase. Secondary ossification results in the replacement of the non-lamellar fibrous bone tissue by the laminar tissue. Increase in bone length occurs through proliferation of cartilage of the growth plate (or epiphyseal plate) the ultimate cartilaginous zone which remains active until growth ceases. Growth is determined by the multiplication of chondrocytes which produce groups of proliferative cells or cartilage mass (Figure 5.6). These cells produce the cartilaginous matrix which is then replaced by bone tissue through the process of endochondral ossification.

The transformation of the long bone model consisting of a cartilaginous matrix during the embryonic stage into definitive bone consisting of laminar bone tissue is achieved after puberty around 24 to 30 months. The production of bone tissue decreases with age as evidenced by plasma osteocalcin (Figure 5.7). This concentration is always higher in the male than in the female.

Bone tissue is under endocrine control during the growth phase (modelling) and during remodelling. Growth cartilage is partially dependent, until bone maturity, on the action of growth hormone

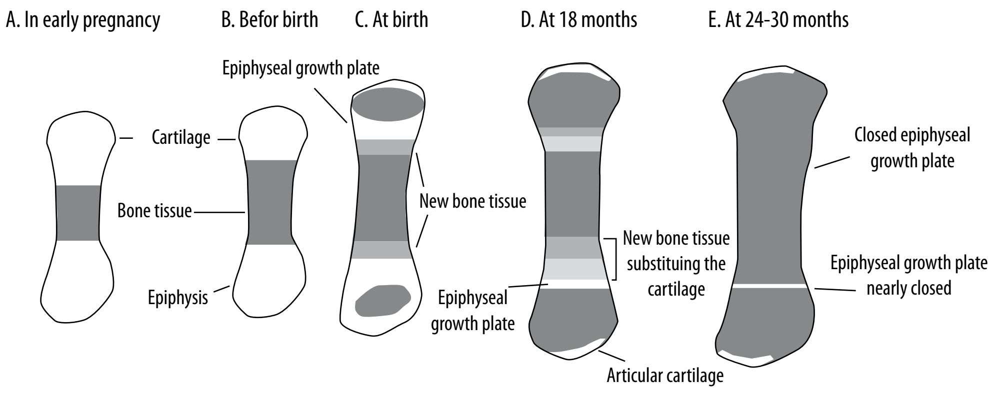

Figure 5.6. Growth of a long bone (adapted from Rossdale and Ricketts, 1978).

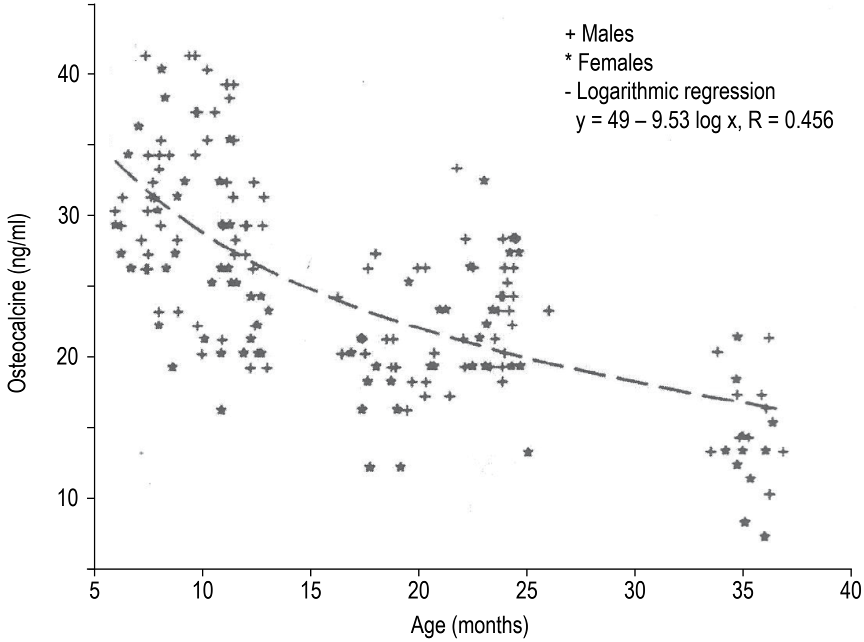

Figure 5.7. Changes in plasma osteocalcin concentration with age (Martin-Rosset, 2005).

(GH) of pituitary origin the secretion of which is stimulated by growth hormone releasing factor, a hypothalamic neuropeptide and partly by IGF-1 secreted largely from the liver under the action of GH as well as the paracrine action of the osteoblasts. GH stimulates elongation growth of bones: partly by directly promoting the differentiation of precursor cells into chondrocytes at the growth plate and partly indirectly by the action of IGF-1 in promoting the proliferation of chondrocytes. These actions, direct by GH and indirect by GH via IGF-1 are potentiated by thyroid hormones. Triiodothyronine (T3) promotes the maturation of chondrocytes as well as the maturation of growth plate cartilage (a direct action of GH). Thyroxin (T4) stimulates the speed of long bone growth through potentiating GH effects.

Sex hormones accelerate longitudinal growth and bone maturation while castration delays this effect and causes osteopenia in the adult. Nevertheless, at puberty the massive endogenous secretion induces the arrest of growth by closing growth plate cartilage. In effect oestrogens block the multiplication of chondrocytes at the growth plate and accelerate their maturation by contributing to calcification of the cartilaginous matrix. Specific hormones of phosphocalcium metabolism: parathormone (PTH), the active metabolite of vitamin D, and calcitonin will only play a predominant role in the remodelling process of bone metaphysis and calcification of the cartilaginous matrix. PTH stimulates the synthesis of IGF-1 which explains the anabolic effect of PTH on bone.

Osteogenesis of long bone and skeletal allometry have major consequences on the mechanical properties of long bones. These have been particularly well studied by INRA on a reference long bone, the canon, in relation to its physical-chemical characteristics. Between birth and the age of

40 months the weight, volume and thickness of the canon bone are a multiple of 2 relative to these measurements at birth, whereas the density has only increased by 20%. Mineral content does not vary significantly with age or weight. Breaking stress (S) or maximum force (Fmax) per unit of area just before breaking: S = Fmax/Age (Figure 5.8A) and the modulus of elasticity (E) or bone axial rigidity: E = ΔS increases exponentially with weight and age (Figure 5.8B).

Inverse ultimate deformation (εu) determined before breaking, when the canon bone is subjected to a breaking force, decreases very rapidly with age and liveweight (Figure 5.9).

5.1.6 Variable factors of growth and development

Growth and development are determined by genetic potential and are modulated by the effects of environmental factors.

5.1.6.1 Genetic effect

Liveweight and adult size range from 1 to 5 respectively in the pony (Chapter 8) and the draft horse. The individual genetic influence on size is high as the heritability coefficient (h2) is 0.35, but it varies from 0.12 to 0.63 for various size parameters (height at withers, heartgirth, canon circumference, etc.).

Draft horses are later developing than light horse breeds. The Arab breed is slower developing than the English Thoroughbred. The sport and leisure breeds, Selle Francais or Anglo-Arab, are slower than race horse breeds, Thoroughbred and Standardbred (Figure 5.10). But this genetic effect is moderated by the definite effect of the maternal size since, strictly speaking, the influence of the

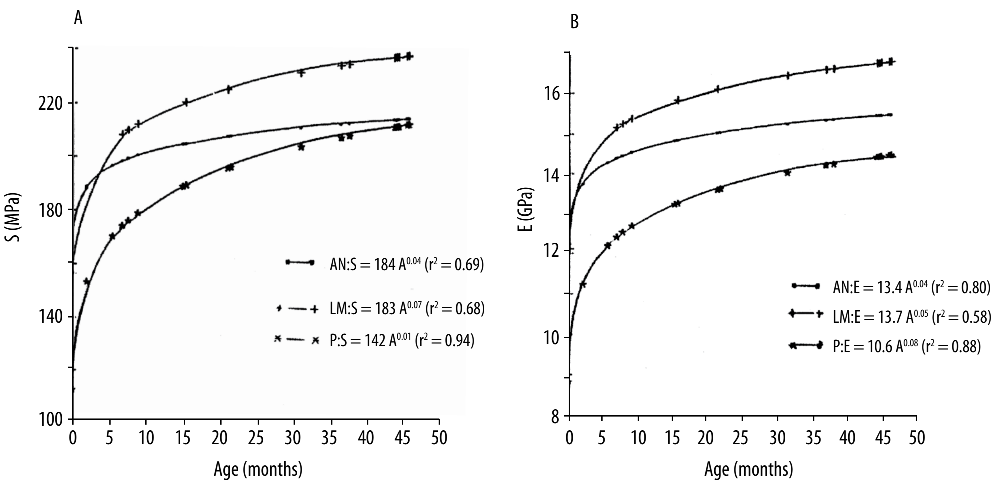

Figure 5.8. Evolution with age (A) of the biomechanical properties of the canon bone in cranial (AN), lateral, and medial (LM) and caudal (P) quadrants. (A) breaking stress. (B) modulus of elasticity (Bigot *et al.,* 1996).

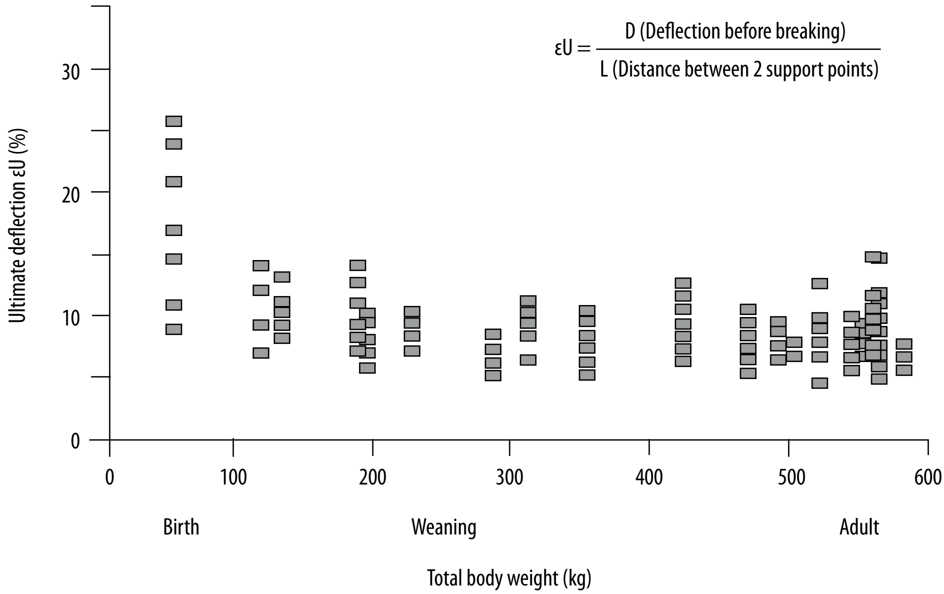

Figure 5.9. Evolution of ultimate deformation (εU) (Bigot *et al.*, 1996).

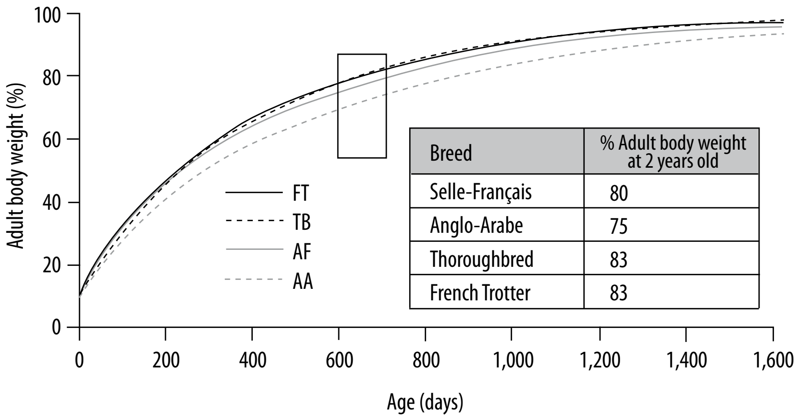

Figure 5.10. Percentage of liveweight attained at various ages in light breed horses (TB = Thoroughbred; FT = French Trotters; SF = Selle Francais; AA = Anglo-Arab) (Heugebaert *et al.*, 2010).

stallion is only 70% of that of the mare. These effects have been demonstrated through reciprocal cross experiments between breeds of extreme sizes (Table 5.1).

Breed effect on liveweight and daily gain is very high. Daily gain is always linked to the adult body size of the breed. For example, it ranges from 0.25 to 1.0 to 1.3 kg between 6 and 12 months for ponies, light breeds and draft horse weighing respectively 250, 450 and 900 kg adult liveweight. Variation

Table 5.1. Effect of maternal size on foal liveweight at birth.

Mare	Stallion	Birth weight	References
Shetland	Shire	17	Walton and Hammond, 1938
Shire	Shetland	53	
Shetland	Shetland	17	
Shire	Shire	70	
Shetland	Mecklenbourg	27	Flade, 1965
Mecklenbourg	Shetland	48	
Shetland	Shetland	21	
Mecklenbourg	Mecklenbourg	60	

within breed is much less: from 15 to 20% and probably inherited, but that has not been evaluated as it has in other species. In contrast liveweight heritability is from 0.17 to 0.27 in Warmblood breeds.

The carcass weight of various draft breeds of horses fattened then slaughtered at the same age in the body of studies conducted by INRA and IFCE, between 12 and 30 months is much greater in the very large breeds (Percherons: 407 kg) than in the smaller draft breeds (Ardenais, Boulonnais, Breton, Contois: 339 to 363 kg) The carcasses of Comtois and Ardennais contain much more fat (11.9 and 14.2% adipose tissue) and less muscle (69.2 and 68.2%) than those of other breeds (8.6 to 10.8% for adipose tissue and 70.8 to 71.9% muscle) because the relative growth of the tissues is very different (Table 5.2). This difference in fattening ability of different breeds is equally true when compared at the same percentage of adipose tissue in the empty body. The different genetic types arrive at the same amount of fattening at significantly different weights: 471 kg for the Comtois; 486 and 508 for

Table 5.2. Variation in relative tissue growth in draft horse breeds between 12 and 30 months of age (Martin-Rosset *et al.*, 1983).

	Breeds (number)	Average allometric coefficient				
		Ardennais (13)	Boulonnais (15)	Breton (13)	Comtois (17)	Percheron (15)
Factorial effect of weight						
Carcass	356.1	0.993	1.0003	1.000	1.001	1.003
Muscles	250.5	0.985[a]	1.022[a]	1.006[ab]	0.970[acd]	1.019[b]
Adipose tissue	38.4	1.106[a]	0.784[b]	0.998[ab]	1.320[ac]	0.864[ab]
Bone	54.6	0.968[a]	1.064[b]	1.04[ad]	0.915[bc]	1.057[bd]
Carcass composition at a weight of 356 kg						
Muscles		69.2	71.9	70.8	68.2	71.7
Adipose tissue		11.9	8.6	10.8	14.2	9.3
Bone		14.8	16.3	15.3	14.0	16.2

Data with different superscripts (a, b, c, d) are statistically different.

the Bretons and Ardennais; 519 and 580 for the Boulonnais and Percherons. Differences appear more limited among light horse breeds at least for muscles (Table 5.3).

5.1.6.2 Sex effects

Females develop early than males regardless of breed, but differences depend on body region. At 12 months of age, chest width, height and length of hind limb and length of trunk are greater in females. Conversely the development of the fore limb is greater in males. Canon bone circumference is greater in males at 18 months in light horse breeds but only at 30 months in draft breeds. Adult liveweight is 10% greater in males. This difference is already significant at 18 and 30 months respectively in stallions and geldings.

Carcass and empty bodyweights are 10% greater in draft breed males between 12 and 30 months according to measurements made by INRA (Table 5.4). At the same empty bodyweight the proportions of adipose tissue and muscle are greater (+31%) and lower (-1%), respectively, in females. The relative growth of adipose tissue compared to empty bodyweight is homogeneous whereas that of muscle tissue is greater but not significantly in females.

Males are significantly more likely to express osteoarticular pathologies, such as osteochondrosis, than females since they are given very high ration quantities in order to realise their maximum genetic potential for growth (Figure 5.11).

5.1.6.3 Effect of nutrition

Feed intake levels

Live weight and body condition of light horse breeds (or draft) increase with level of feed intake but the effect diminishes with age (Figure 5.12).

Table 5.3. Relative growth of principal muscle regions (Y) compared to liveweight (X) in saddle horses and Thoroughbreds (adapted from Gunn, 1975).

Muscles in major muscle groups	Allometric Coefficient	
	Light horses	Thoroughbreds
Forequarters		
Distal	1.04	1.02
Proximal	1.01	1.05
Posterior	0.99	1.04
Hindquarters		
Distal	0.97	1.11
Proximal	1.05	1.15

Table 5.4. Influence of sex on relative growth and body composition in draft horses (adapted from Martin-Rosset *et al.*, 1983).

Animals	Males (n=39)	Females (n=34)
Allometric coefficient related to empty bodyweight		
Carcass	1.04	1.04
Muscles	0.91[a]	1.04[b]
Adipose tissues	2.13	2.13
Os	0.71	0.71
Carcass composition at a bodyweight of 356 kg (%)		
Muscles	70.7	70.0
Adipose tissues	9.4	12.3
Bone	15.7	14.9

Data with different superscripts (a, b) are statistically different.

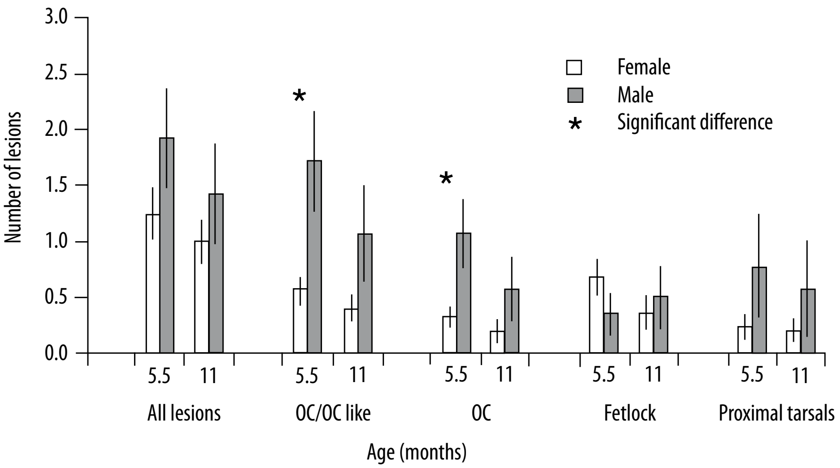

Figure 5.11. Effects of very high dietary intakes on the appearance of osteochondrosis lesions in young colts (M) vs fillies (F) in sport horse breeds at 5 and 11 months of age (Donabédian *et al.*, 2006).

Beginning in 1984, INRA has established nutritional models to evaluate the energy and protein requirements of young horses in each age group for these reasons (Section 5.2.1.1). Live weight and body condition can be modified by feed intake levels but the effect on condition depends on the live weight of the foal at weaning. This has been shown experimentally between 6 and 12 months when comparing two growth models: curvilinear vs linear, in light horse foals, heavy or light at weaning due to prior conduct, management, and feeding conditions (Figure 5.13). In foals that are heavy at weaning variations in body size (wither height) and live weight were similar regardless of the model and the animals had the same live weight and body size at 36 months. The lighter foals at weaning reached essentially the same live weight at 36 months regardless of model but their form is always

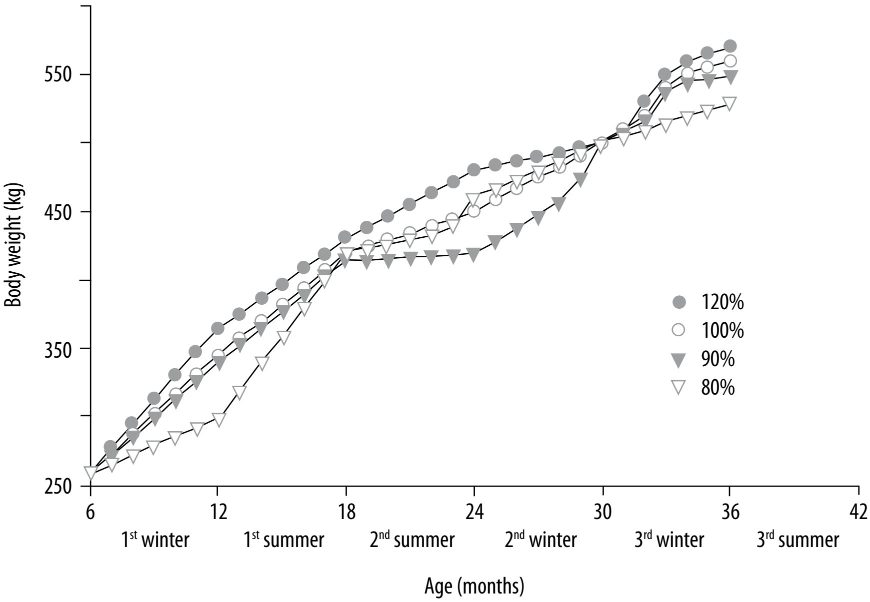

Figure 5.12. Influence of level of feed intake on live weight of light horse breeds during winter (adapted from Bigot *et al.*, 1987).

reduced (linear model) or very reduced (curvilinear model) and in all cases much less than the foals that were heavy at weaning. From 2 years in particular the body size of the light at weaning foals grew according to the curvilinear model and reached a plateau. The live weight of the foal at weaning is therefore a determinant of body form and feeding patterns needs to be adapted to this result.

Compensatory growth

Young horses that have moderate dietary intakes compared to high intake levels for 3 consecutive winters between weaning and 42 months of age are capable of attaining the same live weight at the same age even on pasture as they will undergo compensatory growth if the quantity and quality of the pasture is sufficient (Figure 5.14). The compensation is linked to growth and therefore to the level of feed intake during the winter as well as the duration of the limitation during the preceding winter (Chapter 10). The capacity for compensatory growth diminishes with age.

Effect of level of feed intake on tissue development

Bone tissue development and its biomechanical properties, and the appearance of lesions are influenced by the level of feed intake and the resulting weight gain. In a study two groups of sport horses received, from birth to 12 months 100 or 150% of daily feed allotment recommended by INRA to achieve, respectively, moderate or maximum growth. Live weight, body size and ossification evaluated by the diameter of the canon bone and mineral density of the canon bone were all increased in the higher feed intake group. The number of trabeculae decreased in the high intake group while the space between increased in the canon bone. Frequency of lesions increased, notably in males

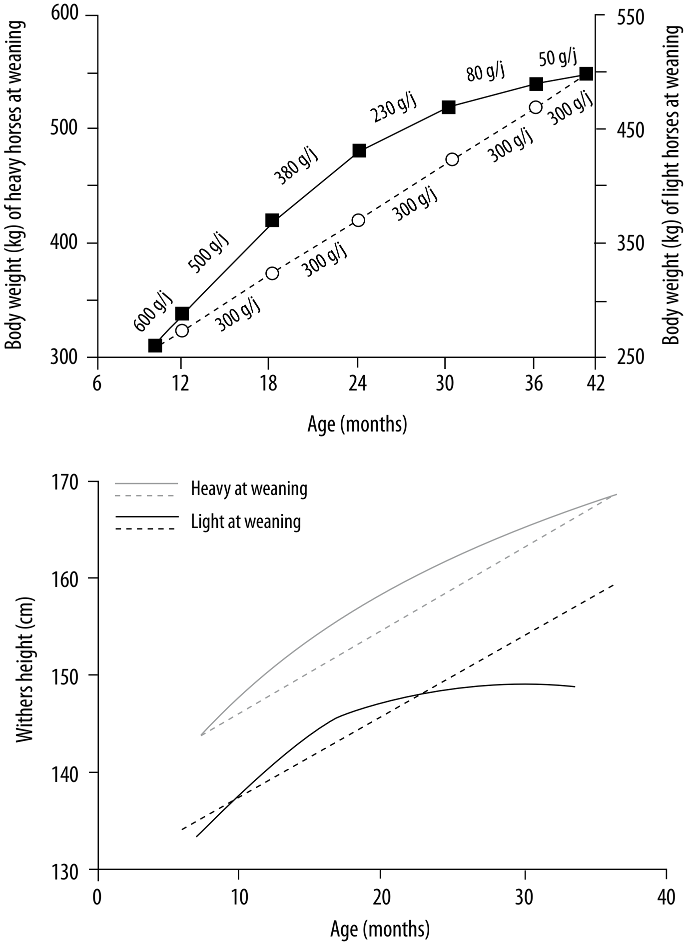

Figure 5.13. Influence of feed intake during the winter on the body size of light horse breeds between 6 and 42 months of age (Trillaud-Geyl *et al.*, 1992).

(Figure 5.15). High feed intakes result in a level of risk and it is necessary to comply with the relevant recommendations to achieve optimal growth.

In another study conducted by INRA, two groups of young sport horses achieved, between 6 and 24 months two rates of limited or moderate growth: 350 vs 450 g/d. The thickness of the cortex and the mechanical characteristics (moment of inertia) of the canon bone were +20 and +37% superior, respectively, in the rapidly growing group.

Adipose tissues were also affected by the level of food intake in a similar manner to the studies by INRA and IFCE on fattening draft horses. The proportion of adipose in the carcass of the foals slaughtered at 12 months was 22% greater in the group receiving 30% more energy than the control group while the proportion of muscle was 4% less.

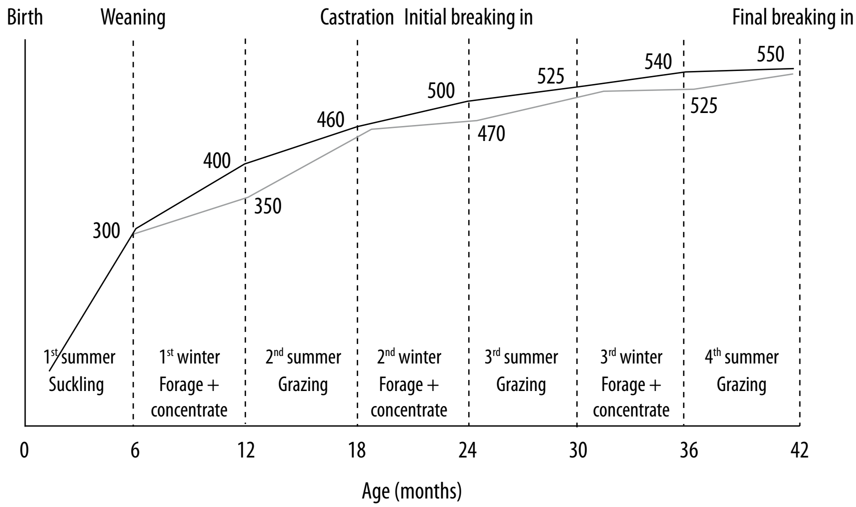

Figure 5.14. Winter growth and summer compensatory growth in light breed horses (adapted from Bigot *et al.*, 1987; Trillaud-Geyl *et al.*, 1990).

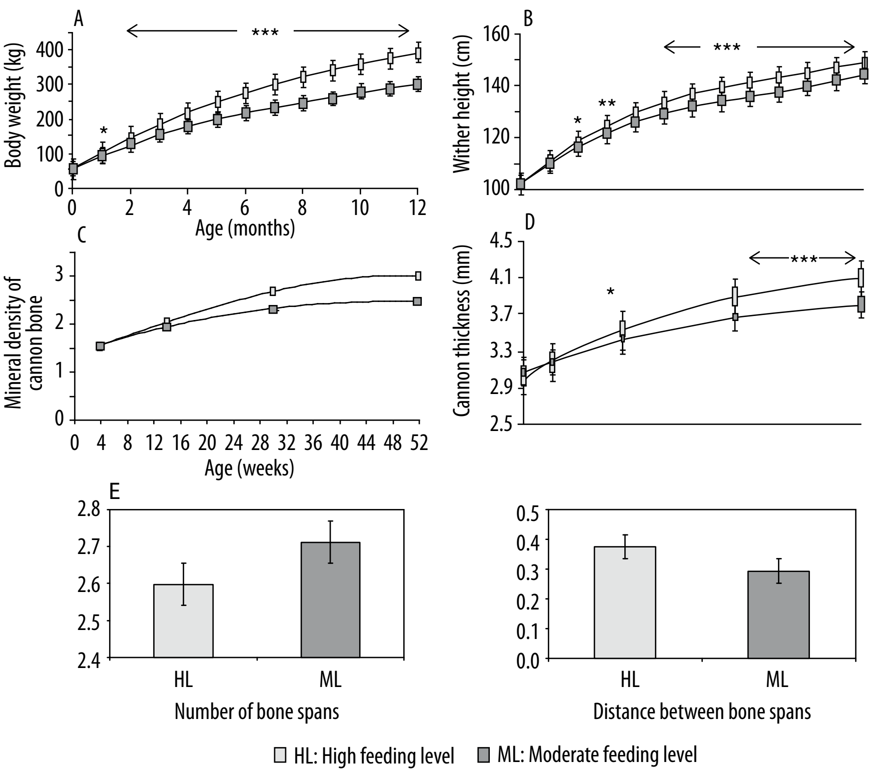

Figure 5.15. Effect of feed intake on characteristics of bone tissue in light horses. (A) body weight, (B) wither height, (C) cannon bone thickness, (D) mineral density of cannon bone and (E) trabecular structure of cannon bone (adapted from Donabédian *et al.*, 2006).

Effect of nutritional balance on the quality of bone tissue

Excess energy intake (+30%) compared to protein intake increases the number of osteo-articular lesions (osteochondrosis) while the converse excess has no effect. The excess energy produces an increased concentration of insulin and induces a hypothyroidism which results in limiting the differentiation of chondrocytes and the synthesis of proteoglycans. Recent studies at INRA have shown that elevated feed intakes, but nutritionally well balanced and containing a starch concentration less than 30% of the dry matter ingested, to produce a submaximal growth, is not conducive to the appearance of osteochondritic lesions.

An imbalance in calcium or phosphorus, if the Ca:P ratio is in the range of 1.5 to 2.0, will not have a direct effect on development of osteochondrosis lesions unless it is associated with another imbalance, especially an excess of energy.

In contrast, copper deficiency augments the number of osteochondrosis lesions because of the increase in the fragility of connective tissue between the calcified cartilage and the primary spongiosa consecutive to a defect in collagen cross-linkage and a change in matrix remodelling.

A deficiency of vitamin D: 1,25OH_2 (D3) results in an increase in the appearance of lesions by halting endochondral ossification. This defect could be due to reduced availability of calcium and phosphorus related to a deficit in the contribution of vitamin D associated with limited production of a metabolite of vitamin D (24,25OH_2) which normally stimulates the synthesis of proteoglycans by chondrocytes and the differentiation of epiphyseal cartilage.

Effect of the nature of the diet

In nursing foals live weight gain is directly associated with the quantity of milk ingested up to 2 months of age according to the model established by INRA (Section 5.2.1.2). After this, daily weight gain decreases as the foal starts to consume forage.

In the foal at weaning daily live weight gain is higher (+ 18%) as 2 kg of concentrate feed is provided from 4 months of age. Weight gain is higher when the concentrate contains 22% crude protein provided in the form of milk powder compared to soya or contains a large proportion of lactose in the form of whey ultrafiltrate compared to a cereal.

After weaning daily live weight gain is closely related to the nature of the forage base. INRA and IFCE have demonstrated in sport horses that daily live weight gain is greater between weaning and 3 years when young horses are fed, in winter, with a diet based on corn silage or partially wilted forage (wrapped) than with diets based on hay offered *ad libitum* and supplemented to balance rations in all cases (Figure 5.16).

The body composition of young horses is very sensitive to the composition of the diet as has been shown by INRA and IFCE in foals of draft horses fattened with a diet based on hay or corn silage after weaning and slaughtered at 12 months. The foals fed corn silage had a greater live weight (+5%) and a higher adipose tissue content in the carcass (+22%).

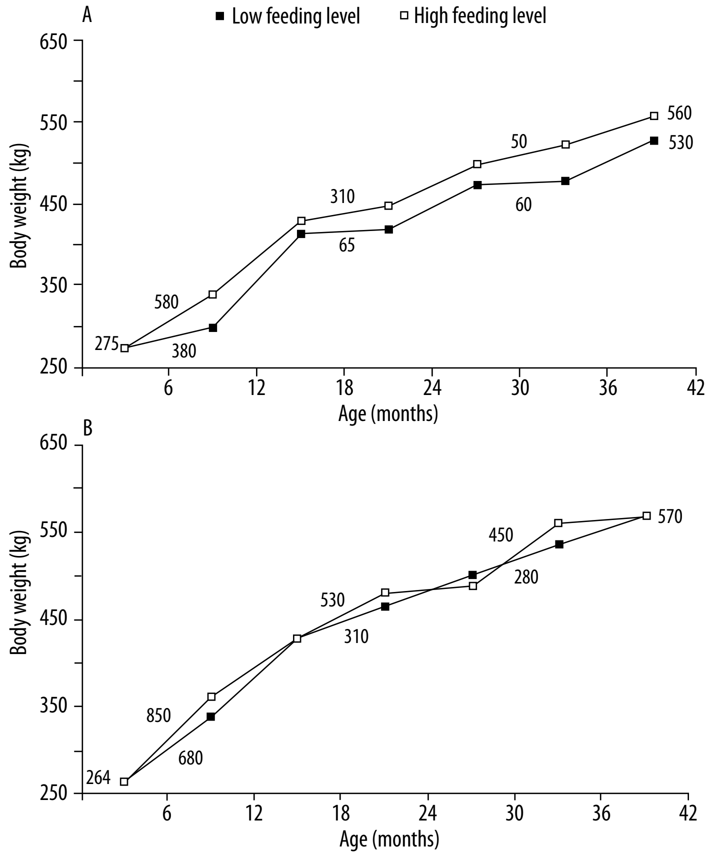

Figure 5.16. Effect of the nature of the forage on growth of sport horses in winter (Trillaud-Geyl and Martin-Rosset, 2005).

5.1.6.4 Effect of exercise

Bone mass production is stimulated by moderate exercise, while bone remodelling is favoured by a reduction in activity. The process is reversible. There should be a response curve to the intensity of work and an optimal threshold for optimum efficiency in horses as has been established in humans, but this remains to be determined in horses.

The thickness of the canon wall (cortex) and its density increases with work in the horse in training. The collagen fibres in the canon bone are oriented in the same direction, while the linkages between the fibrils increase and favour the regulation of mineralisation. The mechanical properties of the canon bone are also improved by exercise up to an optimum which remains to be determined. It depends on the speed and duration of exercise as well as repetition during the training period.

Muscle mass increases when the young horse commences work. This increase is added to the increase in muscle due to growth. The muscle mass due to work has never been measured. It is likely that this is done at the expense of increased fat tissue. In any case the mass of the latter does not increase.

5.2 Nutritional requirements

5.2.1 Energy and protein requirements

5.2.1.1 After weaning

Methods

Requirements have been determined by the universal method of feeding trials. This consists of measuring the relationships between the energy or protein consumed, weight and weight gain of the measured animals, sport horses (Selle Francais or Anglo-Arab) or draft (Ardennais, Breton, Boulonnais, Comtois, Percheron). Numerous feeding trials have been conducted at the INRA experimental stations of Clermont-Ferrand/Theix and IFCE at Chamberet (Correze) between 1970 and 2000, yearly using 100 to 400 horses.

These trials had as objectives to study the utilisation of various feeds or types of diets based on hay, silages (grass and corn) and wilted forage (wrapped). The duration of the trials was on average 150 days during winter. The horses were stabled in free stalls. They were fed forages *ad libitum* supplemented with concentrates and the quantities ingested were measured daily. Animals were weighed every 14 days. Energy and protein values of the feeds were determined from their chemical composition using the INRA techniques presented in Chapter 1 and the tools reported in Chapter 12.

Feed intakes were grouped by periods of 21 days. For each period the average weight and weight gain for the horses was calculated from growth curves fitted by regression in order to limit the fluctuation associated with digestive contents.

From each trio of data: live weight (LW), daily live weight gain (G) and the energy (UFC) or protein (g MADC) ingested daily information could then be obtained step by step along the whole period of the feeding trial.

An equation of the following form has been obtained from collective information:

Energy or protein ingested/d = $aLW^{0.75} + b\ LW^{0.75}\ G^{(1.4)}$

The form of this equation allows for dividing the ingested energy or protein into two fractions: one proportional to the metabolic weight ($LW^{0.75}$), which is analogous to cost of maintenance, the other expresses the calorific value of growth which is a function of its intensity (G) and of the live weight of the animal ($LW^{0.75}$). The exponent d=1.4 corresponds to the allometry of the adipose tissues in the entire body of the horse as measured by INRA. It is applied in the estimation of energy requirements. For protein requirements the exponent is 1 because the allometry of muscle is only 1.1 since the protein content of the entire body and of the weight gain is very similar. The exponent

0.75 is identical to that used for the maintenance requirement (Chapter 1). This allows a better comparison of ingestion (in UFC or g of MADC/$kg^{0.75}$) at different weights.

The initial equation may be simplified mathematically for the daily energy requirement:

Energy ingested/d in UFC/kg $LW^{0.75} = a + bG^{1.4}$

While the equation for daily protein requirement is:

Protein ingested in g MADC/d = c $LW^{0.75}$ + dG

Results: energy requirements

The estimated requirements are very accurate for breeds and for variations in the energy requirements with live weight, daily weight gain and calorific value of the gain. In light horse foals it appears that:

- For the same daily gain of 1 kg the total energy requirement is 4.9 UFC at 250 kg live weight and 6.4 UFC at 350 kg live weight. The increase relates to both the maintenance requirement +1.1 UFC (3.8 UFC at 250 kg and 4.9 UFC at 350 kg) and with the energy cost of each kg of gain: +0.4 UFC (1.1 UFC at 250 kg and 1.5 at 350 kg).
- At the same live weight of 300 kg, the maintenance requirement is 4.3 UFC but the energy cost of a kg of growth is +0.8 UFC while growth varies from 0.5 kg (0.5 UFC/d) to 1.0 kg (1.3 UFC/d).

The same illustration can be made for draft breeds but the values will be different since the energy requirements are different.

The energy requirements of light horse breeds are higher than draft breeds at the same weight and daily gain. Their maintenance requirements are greater: about +25%, because the value of the constant (a) is increased (Table 5.5), 0.0578 UFC/$LW^{0.75}$ instead of 0.0476 UFC/$LW^{0.75}$ at 12 months of age. The energy cost of a kg of gain appears to be lower: b=0.0183 instead of b=0.0254 probably

Table 5.5. Relationships between ingested energy (UFC), live weight (LW in kg) and weight gain (G in kg): Y (UFC/kg $LW^{0.75}$/d) = a + $bG^{1.4}$.

Categories	Constants	
	a	b
Light breeds		
6-12 months	0.0602	0.0183
18-24 months	0.0594	0.0252
30-36 months	0.0594	0.0252
Draft breeds		
6-12 months	0.0476	0.0254
18-24 months	0.0476	0.0254
30-36 months	0.0476	0.0254

because the light horse breeds have a lower capacity for growth than draft breeds at the same weight. However, the most rigorous comparison should be made at the same proportion of adult weight. For example in the foal of 12 months where live weight represents 55% of adult live weight and has a daily live weight gain of 1 kg the total energy requirement of the draft horse foal (6.4 UFC) is 12% greater than that of the light horse foal (5.7 UFC). This higher requirement is related to much higher growth (+69%) and greater lipid content of the gain while requirement for maintenance is reduced (-5%). But since the fraction of requirement for maintenance in the total requirement is higher in foals of light horse breeds (+13%) the difference between breeds is reduced.

Results: protein requirements

The variations in protein requirements for each breed related to live weight and weight gain are accurately determined.

- For the same daily growth of 1 kg the total protein requirements are 670 g MADC/d at 250 kg live weight and 733 g MADC at 350 kg live weight. The increase is 63 g MADC. This only includes the requirement for maintenance.
- For the same live weight of 300 kg, the maintenance requirement is 252 g of MADC while the protein requirement increases from 225 g of MADC when growth varies from 0.5 kg (225 g MADC/d to 1.0 kg (450 g MADC/d).

The same observation can be made for draft breeds but the values will be different as the requirements are different.

There are small differences between the protein requirements of light horses and those of draft breeds, for instance at the same weight and daily growth rate, for example, as the value of b indicates (Table 5.6): 450 as compared to 440 at 12 months of age. This is not surprising since the amount of protein in the muscles is considered to be constant and identical (20-22% protein). A comparison at the same proportion of live weight at 12 months, for example, also confirms this observation. The total requirement of draft breed foals is only 10% greater essentially because the maintenance

Table 5.6. Relationship between protein ingested (g MADC/d) live weight ($LW^{0.75}$) and gain in weight (G in kg): Y (g MADC/d) = a $LW^{0.75}$ + b G.

Categories	Constants	
	a	b
Light horses		
6-12 months	3.5	450
18-24 months	2.8	270
30-36 months	2.8	270
Draft horses		
6-12 months	3.5	440
18-24 months	2.8	370
30-36 months	2.8	370

requirement is 28% greater while the requirement for growth is very close (2%) and it represents 57 and 64% respectively of the total requirement for draft breeds and light horses.

Young horses also have a specific requirement for certain amino acids. Actually the only clearly established requirement is for lysine. The requirement increases to 0.054, 0.087 and 0.105% of the requirement for protein (MADC) from 3 to 6 months and 6 to 12 months and beyond.

5.2.1.2 Before weaning

The requirements between 0 and 2 months can be estimated using the feeding trial method during the time where foal growth depends entirely on milk production by the mare and by using the production-growth relationship established experimentally by INRA.

Live weight gain (g/d) = + a_1 or a_2 X

Where X = milk production in kg;
a_1= slope during the first month;
a_2= slope during the second month.

During the first and second month of lactation 10.6 kg to 13.7 kg of milk respectively are required per kg of live weight gain in foals.

5.2.2 Mineral requirements

Requirements for minerals have been established using the factorial method, the only one available as no results of feeding trails are available, as is the case for energy and protein. It consists of estimating the net requirement or the loses, taking into account the true mineral digestibility if it is known (Chapter 1, Table 1.16). The requirements proposed by INRA (Martin-Rosset, 1990) have been modified taking into account work conducted in the interval and compiled by EAAP (Julliand and Martin-Rosset, 2005) in Europe and Conference of Feed Manufacturers, KER (2001) and NRC (2007) in the USA.

5.2.2.1 Calcium

The maintenance expense in the young horse is 36 mg/kg/d and the cost for weight gain is 16 g/kg/d. True digestibility at maintenance is 50%. In contrast better account can be taken of true digestibility for growth: 70% from 0 to 12 months; 50% to 18 months; 30% at 24 months and not working for the two last age classes. The general equation proposed by NRC (2007) can be used to calculate requirements, adapting it to the age classes to take into account the reduction in true digestibility with age and the effect of the composition of the diets in use (digestibility of calcium in forages ranges from 40 to 70%).

0 to 12 months:
g Ca/d = (0.036 g/0.50 × LW kg) + (16 g/0.70 × G kg)
or g Ca/d = (0.072 g × LW kg) + (23 g × G kg)

12 to 24 months:

$$g\ Ca/d = (0.036\ g/0.50 \times LW\ kg) + (16\ g/0.50 \times G\ kg)$$

or $$g\ Ca/d = (0.072\ g \times LW\ kg) + (32\ g \times G\ kg)$$

24 to 36 months:

$$g\ Ca/d = (0.036\ g/0.50 \times LW\ kg) + (16\ g/0.30 \times G\ kg)$$

or $$g\ Ca/d = (0.072\ g \times LW\ kg) + (53\ g \times G\ kg)$$

5.2.2.2 Phosphorus

The maintenance cost is 18 mg/kg LW/d while the cost for weight gain is 8 g/kg/d. True digestibility at maintenance is 35%. To be coordinated with the variation in the true digestibility of calcium with age a variation in the digestibility of phosphorus is as follows: 55% from 0 to 12 months; 45% from 12 to 24 months; 35% from 24 to 36 months and not working in the latter two age classes. The requirement can then be calculated:

0 to 12 months:

$$g\ P/d = (0.018\ g/0.35 \times LW\ kg) + (8\ g/0.55 \times G\ kg)$$

or $$g\ P/d = (0.051\ g \times LW\ kg) + (15\ g \times G\ kg)$$

12 to 24 months:

$$g\ P/d = (0.018\ g/0.035 \times LW\ kg) + (8\ g/0.45 \times G\ kg)$$

or $$g\ P/d = (0.051\ g \times LW\ kg) + (18\ g \times G\ kg)$$

24 to 36 months:

$$g\ P/d = (0.018\ g/0.35 \times LW\ kg) + (8\ g/0.35 \times G\ kg)$$

or $$g\ P/d = (0.051\ g \times LW\ kg) + (23g \times G\ kg)$$

5.2.2.3 Magnesium

The maintenance cost is 6 mg/kg/d and digestibility is 40%. Taking into that the variation in true digestibility varies with age during growth: from 70% from 0 to 12 months; 60% from 12 to 24 months; to 50% from 24 to 36 months while the cost of gain is 1.0 g/kg. The requirements can then be calculated:

0 to 12 months

$$g\ Mg/d = (0.006/0.40 \times LW\ kg) + (1\ g/0.70 \times G\ kg)$$

or $$g\ Mg/d = (0.015\ g \times LW\ kg) + (1.43 \times G\ kg)$$

12 to 24 months

$$g\ Mg/d = (0.006/0.40 \times LW\ kg) + (1\ g/0.60 \times G\ kg)$$

or $$g\ Mg/d = (0.015\ g \times LW\ kg) + (1.67 \times G\ kg)$$

24 to 36 months

$$g\ Mg/d = (0.006/0.40 \times LW\ kg) + 1g\ /0.50 \times G\ kg)$$

or $$g\ Mg/d = (0.015\ g \times LW\ kg) + (2.00 \times G\ kg)$$

5.2.2.4 Potassium

The costs of maintenance and growth are respectively 50 mg/kg LW/d and 1.5 g/kg gain. The true digestibility at maintenance is 80% and for growth, 50%. The calculated requirement for the young horse for the various age classes is:

g K/d = (0.05 g/0.80 × LW kg) + (1.5 g/0.50 × G kg)
or K/d = (0.063 g × LW kg) + (3.0 g × G kg)

5.2.2.5 Sodium

The sodium cost amounts to 18 mg/kg LW/d at maintenance and 0.85 g/kg of gain. The true digestibility of sodium is 90% at maintenance and 80% during growth. The requirement is therefore calculated as:

g Na/d = (0.018/0.90 g × LW kg) + (0.85 g/0.80 × G kg)
or g Na/d = (0.02 g × LW kg) + (1.1 g × G kg)

5.2.2.6 Chloride

INRA indicated that requirements were met by providing salt (sodium chloride) (INRA, 1990). Since then specific requirements have been re-evaluated for maintenance as 80 mg/kg LW/d to maintain acid-base equilibrium and from 2.5 to 13 mg/kg gain. True digestibility is considered to be 100% for maintenance and growth. Requirements are therefore calculated as:

0 to 6 months:
g Cl /d = (0.08 g Cl × LW kg) + (0.013 g Cl × G kg)

6 to 12 months:
g Cl /d = (0.08 g Cl × LW kg) + (0.005 g Cl × G kg)

12 to 24 months:
g Cl /d = (0.08 g Cl × LW kg) + (0.0025 g Cl × G kg)

5.2.3 Microminerals

Microminerals requirements expressed as mg/kg dry matter intake (DMI) proposed by INRA (1990), have not been modified in the absence of new convincing results with the exception of those for iron which have been lowered to 50 mg/kg DMI (Chapter 2, Table 2.1). They are reported for young horses of 6 to 12 months, 18 to 24 months and 32 to 36 months in Chapter 2, Table 2.1. There is no proven requirement for chromium, fluorine or silica in the available literature.

5.2.4 Vitamins

The requirements proposed by INRA (Martin-Rosset, 1990) have had increased in vitamin E to 80 IU/kg DMI for the 6 to 12 months period and to 60 IU/kg DMI afterwards and marginal adjustments in vitamin A. They are expressed in IU per kg dry matter intake for young horses 6 to 12 months of age, 18 to 24 months and 32 to 36 months as stated in Chapter 2, Table 2.1.

5.3 Recommended allowances

5.3.1 Before weaning

Requirements of the young foal have been evaluated by INRA:

- Between 0 and 2 months: 0.039 UFC/kg LW and 0.044 UFC/kg LW (or 0.139 UFC and 0.119 UFC/$kg^{0.75}$); 4.0 g MADC to 4.5 g MADC/kg LW (or (12.2 g MADC and 14.3 g MADC/kg $LW^{0.75}$) respectively for growth of 1,200 and 1,500 g/d.
- Between 3 and 6 months: 0.023 UFC and 0.024 UFC/kg LW (or 0.088 UFC and 0.093 UFC/kg $LW^{0.75}$); 2.4 g MADC/kg LW and 2.6 g MADC/kg LW (or 8.8 g MADC and 10.2 g MADC/kg $LW^{0.75}$) respectively for growth rates of 750 and 1,100 g/d)

The daily requirement for lysine will be 0.054% of the requirement by MADC.

5.3.2 After weaning

5.3.2.1 Origin of the data

Nutritional requirements were measured in feeding trials conducted by INRA at the Clermont-Ferrand, Puy de Dôme Station and National Stud Station at Chamberet, Correze between 1970 and 2000, under normal management conditions. Animals were in groups, housed in free stalls with a paddock from 2 years of age during the winter and in rotated pastures in the summer from 12 months of age. Feeding trials were run with different objectives of maximum or moderate growth on several types of horses (light – draft), of different ages, receiving a variety of different feeding regimes. The diets provided corresponded well with realistic situations so that it is possible to provide practical recommendations according to production objectives: sport horses, leisure horses, draft horse for work or being fattened for slaughter.

Feed intakes are recommended for sport or leisure horses or for draft breeds. The quantities proposed for sport horse destined for competition may be used for race horses up to 18 months (that is, during the raising period when, in the strictest sense, the rate of growth is chosen that is adapted to the ultimate objective). Separate tables provide the allotments for the following period that includes specific training for sport horse racing or track racing.

5.3.2.2 Tables

Feed intakes are proposed by adult live weight class (450 to 800 kg) and for each class as a function of age for foals born in the spring. For each age class two growth rates are proposed according to the production strategies. Distinction is made between light breeds and draft horses from 600 kg adult live weight.

Tables of recommended daily nutrients and intake allowances (Table 5.7 to 5.17) give feed intakes corresponding to the total requirements for maintenance and growth for energy, protein, minerals (Ca, P, Mg, Na, Cl and K) and the trace elements (Cu, Zn, Co, Se, Mn, Fe and I).

Table 5.7. Recommended daily nutrients allowances and intake allowances during growth for light horses with an adult live weight of **450 kg**.

Age (months)	Average weight[1] during the period (kg)	Growth		Daily nutrients allowances																			Dry matter intake[4] (kg)
		Rate level	Gain in bodyweight (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
3-6[2]	187	Optimal	700-900	4.5	486	26	32	22	4	5	15	14	55	275	1.1	1.1	220	275	1.1	18,900	3,300	440	4.5-6.5
3-6[3]	155	Moderate	550-650	3.6	372	20	25	17	3	4	12	11	50	250	1.0	1.0	200	250	1.0	17,300	3,000	400	4.0-6.0
6-12[2]	270	Optimal	550-600	4.6	501	44	33	22	5	6	22	18	70	350	1.4	1.4	280	350	1.4	24,200	4,200	560	6.0-8.0
6-12[3]	234	Moderate	350-400	3.9	378	33	26	18	4	5	19	16	65	325	1.3	1.3	260	325	1.3	22,400	3,900	520	5.5-7.5
18-24[2]	405	Optimal	150-200	5.6	300	32	33	24	6	8	32	26	90	450	1.8	1.8	360	450	1.8	31,500	4,500	540	8.0-10.0
18-24[3]	369	Moderate	250-300	5.3	310	33	35	24	6	8	30	24	85	425	1.7	1.7	340	425	1.7	29,800	4,300	510	7.5-9.5
24-30[2]	437	Optimal	100-150	5.8	301	32	38	25	7	9	35	28	100	500	2.0	2.0	400	500	2.0	34,500	5,000	600	9.0-11.0
30-36[3]	430	Moderate	50-100	5.7	288	30	35	24	7	9	34	27	90	450	1.8	1.8	360	450	1.8	31,500	4,500	540	8.0-10.0
36-42[3]	444	Moderate	50-100	5.8	292	31	36	24	7	9	36	28	100	500	2.0	2.0	400	500	2,0	34,500	5,000	600	9.0-11.0

[1] Average bodyweight during the period.

[2] Racing breeds (not in training).

[3] Sport horse breeds.

[4] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 5.8. Recommended daily nutrient allowances and intake allowances during growth for light horses with an adult live weight of **500 kg**.

Age	Average	Growth		Daily nutrients allowances																			Dry matter
(months)	weight[1] during the period (kg)	Rate level	Gain in bodyweight (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[4] (kg)
3-6[2]	208	Optimal	800-1000	5.0	541	29	36	24	4	5	17	15	60	300	1.2	1.2	240	300	1.2	20,700	3,600	480	5.0-7.0
3-6[3]	173	Moderate	650-750	4.0	415	22	29	19	4	5	14	13	55	275	1.1	1.1	220	275	1.1	19,000	3,300	440	4.5-6.5
6-12[2]	300	Optimal	600-700	5.1	567	49	37	25	5	7	24	21	75	375	1.5	1.5	300	375	1.5	25,900	4,500	600	6.5-8.5
6-12[3]	260	Moderate	400-500	4.3	425	37	29	20	5	6	21	18	70	350	1.4	1.4	280	350	1.4	24,200	4,200	580	6.0-8.0
18-24[2]	448	Optimal	200-250	6.1	331	35	38	27	7	9	36	29	98	488	2.0	2.0	390	488	2.0	34,100	4,900	585	8.5-11.0
18-24[3]	410	Moderate	300-350	5.9	344	36	40	27	7	9	33	27	93	463	1.9	1.9	370	463	1.9	32,400	4,600	555	8.0-10.5
24-30[2]	485	Optimal	150-200	6.4	335	35	44	29	8	10	39	31	108	538	2.2	2.2	430	538	2.2	37,600	5,400	645	9.5-12.0
30-36[3]	478	Moderate	50-100	6.2	308	32	39	26	7	10	38	30	98	488	2.0	2.0	390	488	2.0	34,100	4,900	585	8.5-11.0
36-42[3]	493	Moderate	50-100	6.3	315	33	40	27	8	10	39	31	108	538	2.2	2.2	430	538	2.2	37,600	5,400	645	9.5-12.0

[1] Average bodyweight during the period.

[2] Racing breds (not in training).

[3] Sport horse breeds.

[4] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 5.9. Recommended daily nutrient allowances and intake allowances during growth for light horses with an adult live weight of **550 kg**.

Age (months)	Average weight[1] during the period (kg)	Growth		Daily nutrients allowances																			Dry matter intake[4] (kg)
		Rate level	Gain in bodyweight (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
3-6[2]	229	Optimal	900-1100	5.5	595	32	40	27	5	6	18	17	65	325	1.3	1.3	260	325	1.3	22,400	3,900	520	5.5-7.5
3-6[3]	190	Moderate	700-800	4.4	456	25	31	21	4	5	15	14	60	300	1.2	1.2	240	300	1.2	20,700	3,600	480	5.0-7.0
6-12[2]	328	Optimal	650-770	5.5	591	53	39	27	6.	7	26	23	83	413	1.7	1.7	330	413	1.7	28,900	4,100	495	7.0-9.0
6-12[3]	286	Moderate	400-500	4.4	461	40	32	22	5	6	23	19	98	488	2.0	2.0	390	488	2.0	34,100	4,900	585	6.5-8.5
18-24[2]	495	Optimal	250-300	6.6	360	38	44	30	8	10	40	32	103	513	2.1	2.1	410	513	2.1	35,900	5,100	615	9.0-11.5
18-24[3]	451	Moderate	350-400	6.4	369	38	45	30	7	9	36	29	98	488	2.0	2.0	390	488	2.0	34,100	4,900	585	8.5-11.0
24-30[2]	534	Optimal	200-250	7.0	371	39	51	32	9	11	43	34	123	613	2.5	2.5	490	613	2.5	42,900	6,100	735	11.0-13.5
30-36[3]	525	Moderate	50-100	6.6	329	33	42	29	8	11	42	33	108	538	2.2	2.2	430	538	2.2	36,000	5,400	645	9.5-12.0
36-42[3]	542	Moderate	50-100	6.5	337	34	43	29	8	11	43	34	123	613	2.5	2.5	490	613	2.5	42,900	6,100	735	11.0-13.5

[1] Average bodyweight during the period.

[2] Racing breds (not in training).

[3] Sport horse breeds.

[4] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 5.10. Recommended daily nutrient allowances and intake allowances during growth for light horses with an adult live weight of **600 kg**.

Age (months)	Average weight[1] during the period (kg)	Growth: Rate level	Growth: Gain in bodyweight (g/d)	Daily nutrients allowances: UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	Dry matter intake[4] (kg)
3-6[2]	249	Optimal	1000-1,200	6.0	647	35	44	29	5	6	20	19	70	350	1.4	1.4	280	350	1.4	24,200	4,200	560	6.0-8.0
3-6[3]	207	Moderate	800-900	4.8	497	27	35	23	3	5	17	15	65	325	1.3	1.3	260	325	1.3	22,400	3,900	520	5.5-7.5
6-12[2]	360	Optimal	700-800	6.0	661	58	43	30	7	8	29	25	90	450	1.8	1.8	360	450	1.8	31,100	5,400	720	8.0-10.0
6-12[3]	312	Moderate	500-550	5.0	496	43	35	24	6	7	25	21	85	425	1.7	1.7	340	425	1.7	29,300	5,100	680	7.5-9.5
18-24[2]	540	Optimal	260-300	7.1	388	41	48	33	9	11	43	35	113	563	2.3	2.3	450	563	2.3	39,400	5,600	675	10.0-12.,5
18-24[3]	492	Moderate	350-400	6.9	394	41	47	32	8	10	39	32	108	538	2.2	2.2	430	538	2.2	37,600	5,400	645	9.5-12.0
24-30[2]	582	Optimal	250-300	7.5	406	43	57	36	9	11	47	38	133	663	2.7	2.7	530	663	2.7	46,400	6,600	795	12.0-14.5
30-36[3]	573	Moderate	50-100	7.0	350	37	45	31	9	11	46	36	113	563	2.3	2.3	450	563	2.3	39,400	5,600	675	10.0-12.5
36-42[3]	591	Moderate	50-100	7.2	358	35	47	32	9	11	47	37	133	663	2.7	2.7	530	663	2.7	46,400	6,600	795	12.0-14.5

[1] Average bodyweight during the period.

[2] Racing breds (not in training).

[3] Sport horse breeds.

[4] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 5.11. Recommended daily nutrient allowances and intake allowances during training for light horses with an adult live weight of **450 kg**.

Age - Weight -Breed + Growth + Work (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	Dry matter intake[2] (kg)
	Daily nutrients allowances																			
18 Months – Racing – 405 kg^{1} – Optimal growth[1]																				
Light	6.2	343	36	35	24	6	12	38	29	90	450	1.8	1.8	360	720	1.8	31,500	4,500	540	8.0-10.0
Moderate	6.7	379	39	35	24	6	16	45	33	90	450	1.8	1.8	360	720	1.8	31,500	4,500	540	8.0-10.0
24 Months – Racing – 437 kg^{1} – Optimal growth[1]																				
Light	6.4	343	36	41	25	7	13	42	32	100	500	2.0	2.0	400	800	2.0	35,000	5,000	600	9.0-11.0
Moderate	7.0	386	40	41	25	7	17	49	36	100	500	2.0	2.0	400	800	2.0	35,000	5,000	600	9.0-11.0
Intense	7.6	430	44	41	25	7	23	58	40	100	500	2.0	2.0	400	800	2.0	35,000	5,000	600	9.0-11.0
Very intense	8.1	466	47	41	25	7	37	81	52	100	500	2.0.	2.0.	400	800	2.0	35,000	5,000	600	9.0-11.0
36 Months – Sport – 430 kg^{1} – Moderate growth[1]																				
Light	6.3	331	34	35	24	7	13	41	31	95	475	1.9	1.9	380	760	1.9	33,300	4,800	570	8.5-10.5
Moderate	6.8	367	37	35	24	7	17	48	34	95	475	1.9	1.9	380	760	1.9	33,300	4,800	570	8.5-10.5
42 Months – Sport – 444 kg^{1} – Moderate growth[1]																				
Light	6.4	335	35	36	24	7	13	43	32	100	500	2.0	2.0	400	500	2.0	35,000	5,000	600	9.0-11.0
Moderate	7.0	378	39	36	24	7	17	50	34	100	500	2.0	2.0	400	500	2.0	35,000	5,000	600	9.0-11.0
Intense	7.6	422	43	36	24	7	23	60	40	100	500	2.0	2.0	400	500	2.0	35,000	5,000	600	9.0-11.0

[1] See Table 5.15 for growth management period.

[2] Lowest values are chosen for a ration high in concentrates and highest values to maximise forage intake.

Table 5.12. Recommended daily nutrient allowances and intake allowances during training for light horses with an adult live weight of **500 kg**.

Age - Weight -Breed +	Daily nutrients allowances																			Dry matter
Growth + Work (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[2] (kg)
18 Months – Racing – 448 kg[1] – Optimal Growth[1]																				
Light	6.7	373	39	38	27	7	13	43	33	98	488	2.0	2.0	390	780	2.0	34,100	4,900	585	8.5-11.0
Moderate	7.3	415	43	38	27	7	17	50	37	98	488	2.0	2.0	390	780	2.0	34,100	4,900	585	8.5-11.0
24 Months – Racing – 485 kg[1] – Optimal Growth[1]																				
Light	7.1	384	40	44	29	8	15	47	35	108	538	2.2	2.2	430	860	2.2	37,600	5,400	645	9.5-12.0
Moderate	7.4	405	41	44	29	8	19	54	39	108	538	2.2	2.2	430	860	2.2	37,600	5,400	645	9.5-12.0
Intense	8.4	475	48	44	29	8	25	65	45	108	538	2.2	2.2	430	860	2.2	37,600	5,400	645	9.5-12.0
Very intense	9.0	517	52	44	29	8	40	90	59	108	538	2.2	2.2	430	860	2.2	37,600	5,400	645	9.5-12.0
36 Months – Sport – 478 kg[1] – Moderate Growth[1]																				
Light	6.8	351	39	39	26	7	15	46	34	103	513	2.1	2.1	410	820	2.1	35,900	5,100	615	9.0-11.5
Moderate	7.3	394	40	39	26	7	19	53	38	103	513	2.1	2.1	410	820	2.1	35,900	5,100	615	9.0-11.5
42 Months – Sport – 493 kg[1] – Moderate Growth[1]																				
Light	7.0	387	40	40	27	8	15	47	35	108	538	2.2	2.2	430	860	2.2	37,600	5,400	645	9.5-12.0
Moderate	7.6	409	42	40	27	8	19	55	39	108	538	2.2	2.2	430	860	2.2	37,600	5,400	645	9.5-12.0
Intense	8.3	459	46	40	27	8	25	65	45	108	538	2.2	2.2	430	860	2.2	37,600	5,400	645	9.5-12.0

[1] See Table 5.15 for growth management period.

[2] Lowest values are chosen for a ration high in concentrates and highest values to maximise forage intake.

Table 5.13. Recommended daily nutrient allowances and intake allowances during training for light horses with an adult live weight of **550 kg**.

Age - Weight -Breed +	Daily nutrients allowances																			Dry matter
Growth + Work (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[2] (kg)
18 Months – Racing – 495 kg[1] – Optimal Growth[1]																				
Light	7.3	410	43	44	30	8	15	48	36	103	513	2.1	2.1	410	820	2.1	35,900	5,100	615	9.0-11.5
Moderate	7.9	454	47	44	30	8	20	56	40	103	513	2.1	2.1	410	820	2.1	35,900	5,100	615	9.0-11.5
24 Months – Racing – 534 kg[1] – Optimal Growth[1]																				
Light	7.8	429	44	51	32	9	16	51	39	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.0-13.5
Moderate	8.4	470	48	51	32	9	21	60	43	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.0-13.5
Intense	9.2	527	53	51	32	9	28	71	49	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.0-13.5
Very intense	9.8	572	57	51	32	9	45	100	64	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.0-13.5
36 Months – Sport – 525 kg[1] – Moderate Growth[1]																				
Light	7.4	387	38	42	29	8	16	50	37	115	575	2.3	2.3	460	920	2.3	40,300	5,800	690	10.5-12.5
Moderate	8.0	432	42	44	29	8	21	58	42	115	575	2.3	2.3	460	920	2.3	40,300	5,800	690	10.5-12.5
42 Months – Sport – 542 kg[1] – Moderate Growth[1]																				
Light	7.4	395	39	43	29	8	16	52	39	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.0-13.5
Moderate	8.0	445	44	43	29	8	21	59	44	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.0-13.5
Intense	8.7	495	48	43	29	8	28	71	49	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.0-13.5

[1] See Table 5.15 for growth management period.

[2] Lowest values are chosen for a ration high in concentrates and highest values to maximise forage intake.

Table 5.14. Recommended daily nutrient allowances and intake allowances during training for light horses with an adult live weight of **600 kg**.

Age - Weight -Breed +	Daily nutrients allowances																			Dry matter
Growth + Work (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[2] (kg)
18 Months – Racing – 540 kg[1] – - Optimal Growth[1]																				
Light	7.8	441	46	48	33	9	16	52	40	113	563	2.3	2.3	450	900	2.3	39,400	5,600	675	10.0-12.5
Moderate	8.5	490	50	48	33	9	21	61	44	113	563	2.3	2.3	450	900	2.3	39,400	5,600	675	10.0-12.5
24 Months – Racing – 582 kg[1] – Optimal Growth[1]																				
Light	8.3	463	48	57	36	9	16	56	43	133	663	2.7	2.7	530	1,060	2.7	46,400	6,600	795	12.0-14.5
Moderate	9.0	516	53	57	36	9	22	66	48	133	663	2.7	2.7	530	1,060	2.7	46,400	6,600	795	12.0-14.5
Intense	9.9	579	59	57	36	9	29	78	54	133	663	2.7	2.7	530	1,060	2.7	46,400	6,600	795	12.0-14.5
Very intense	10.6	629	63	57	36	9	47	109	70	133	663	2.7	2.7	530	1,060	2.7	46,400	6,600	795	12.0-14.5
36 Months – Sport – 573 kg[1] – Moderate Growth[1]																				
Light	7.8	406	42	45	31	9	16	55	41	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.5-13.5
Moderate	8.5	458	47	45	31	9	22	62	46	123	613	2.5	2.5	490	980	2.5	42,900	6,100	735	11.5-13.5
42 Months – Sport – 591 kg[1] – Moderate Growth[1]																				
Light	8.0	414	41	47	32	9	17	56	42	133	663	2.7	2.7	530	1,060	2.7	46,400	6,000	795	12.0-14.5
Moderate	8.8	473	46	47	32	9	22	65	47	133	663	2.7	2.7	530	1,060	2.7	46,400	6,000	795	12.0-14.5
Intense	9.6	530	51	47	32	9	29	88	54	133	663	2.7	2.7	530	1,060	2.7	46,400	6,600	795	12.0-14.5

[1] See Table 5.15 for growth management period.

[2] Lowest values are chosen for a ration high in concentrates and highest values to maximise forage intake.

Table 5.15. Live weights expressed as a percentage of adult live weight for specific ages of light horses[1].

Adult body weight classes (kg)	Age (months)	Bodyweight as a percentage of adult bodyweight (%)	
		Optimal growth[2]	Moderate growth
	6	48	44
450	12	72	60
500	18	86	76
550	24	94	88
600	30	100	94
	36	100	97
	42	100	100

[1] Individual actual adult bodyweight may be estimated for a young horse by averaging the bodyweights of the sire and dam; if that is not possible the weight of the dam may be used.
[2] Optimal growth is used for race horse breeds (Thoroughbred and Trotter).

5.3.2.3 Live weights

Adult live weights correspond to those of the principal French breeds of race horses, sport and leisure horses and draft breeds. For race horses (Thoroughbreds and Trotters) and sport horses (Selle Francais, Anglo-Arab) the adult live weight was calculated with the aid of specific live weight growth curves and mathematical models developed from weight data recorded in France (INRA, IFCE, ENVA) between birth and 3 to 4 years depending on breed (Figure 5.10). The average adult live weights of Thoroughbreds and Trotters are, respectively, 540 and 560 kg. Average live weight of Selle Français and Anglo-Arabs is 590 kg. Average adult live weights for draft breeds comes from breed standards and research conducted at the centres of IFCE at Chamberet and INRA at Theix during 15 years (Table 5.16 and 5.17). Typical live weight for a specific age can be calculated to serve as a benchmark for the choice of growth models and nutrient intakes taking into account the osteoarticular risk factor (Table 5.15).

5.3.2.4 Choice of growth rate

There are two levels of nutrient intakes proposed for race horses and sport horses in Table 5.7 to 5.10 as a function of the production objectives described in Figure 5.10 and 5.14.

Optimal growth

There is significant growth possible through the genetic potential of the young horse while avoiding overweight related to fattening. This rate of growth will allow the young horse to reach 70% of adult live weight at 12 months without risking the occurrence of osteoarticular pathologies of nutritional origin such as osteochondrosis.

Table 5.16. Recommended daily nutrient allowances and intake allowances during growth for draft horses with an adult live weight of **700 kg**.

Age (months)	Average weight[1] during the period (kg)	Growth: Rate level	Growth: Gain in bodyweight (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	Dry matter intake[2] (kg)
6-12[3]	410	Moderate	650	5.6	590	51	45	31	7	9	33	27	80	400	1.6	1.6	320	400	1.6	27,600	4,800	480	7.5-8.5
18-24[2]	600	Optimal	550	7.0	570	60	61	35	10	13	48	39	115	575	2.3	2.3	460	575	2.3	40,300	5,800	690	10.5-12.5
18-24[3]	560	Moderate	250	6.0	440	46	48	33	9	12	45	36	110	550	2.2	2.2	440	550	2.2	38,500	5,500	660	10.5-11.5
30-36[3]	640	Moderate	50	6.1	380	40	49	34	10	13	51	40	120	600	2.4	2.4	480	600	2.4	42,000	6,000	720	11.5-12.5

[1] Median bodyweight during the period.

[2] Lowest values are chosen for a ration high in concentrates and highest values to maximise forage intake.

Table 5.17. Recommended daily nutrient allowances and intake allowances during growth for draft horses with an adult live weight of **800 kg**.

Age (months)	Average weight[1] during the period (kg)	Growth: Rate level	Growth: Gain in bodyweight (g/d)	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	Dry matter intake[2] (kg)
6-12	460	Moderate	750	6.5	600	52	50	35	8	10	37	31	90	540	1.8	1.8	360	540	1.8	31,100	5,400	720	8.5-9.5
18-24[2]	680	Optimal	630	7.7	600	63	69	46	11	14	54	44	125	625	2.5	2.5	500	625	2.5	43,800	6,300	750	11.5-13.5
18-24	640	Moderate	350	6.7	490	52	57	39	10	13	51	41	120	600	2.4	2.4	480	600	2.4	42,000	6,300	720	11.5-12.5
30-36	730	Moderate	50	6.8	410	43	55	38	11	15	58	46	130	650	2.6	2.6	520	650	2.6	45,500	6,500	780	12.5-13.5

[1] Median bodyweight during the period.

[2] Lowest values are chosen for a ration high in concentrates and highest values to maximise forage intake.

Moderate growth

The young horse may undergo a more limited growth for a short period without reducing its potential of reaching its normal final weight if it receives a liberal diet during the succeeding period (for example high quality pasture in the summer). This will allow, after a slight delay, compensatory growth and the attainment of a normal final live weight and body size similar to the continuously well-nourished horse.

A moderate rate of growth is more common in draft horses as this fits the techno-economic objectives of farm animal management. However, during the period from 20 to 24 months fillies bred at 2 years of age need a higher growth rate. In this case the nutrient intakes recommended in Table 5.16 and 5.17 should be followed.

In all cases it is a mistake to aim for maximum growth for a foal that has, at weaning, a live weight less than 40% of expected adult live weight (average of the weight of its dam and sire) due to limited growth before weaning and not for genetic reasons. Its development (conformation) has a strong probability of slowing considerably from 18 to 24 months of age (puberty) in particular in colts (Figure 5.13). It is best to choose a moderate but continuous rate of growth (i.e. linear) in summer as in winter.

5.3.2.5 Young horses in training

Without doubt this situation has been less researched and for which, therefore, knowledge is very limited. There is little variation in the percentage of muscle in the carcass after weaning, while the percentage of adipose tissue increases during this growing period with no work other than spontaneous activity. In consequence, the amount of protein remains relatively constant while lipid concentration increases. It is also true that the level of energy intake and weight gain are high as the horse is getting older: 2 year olds compared with 12 to 18 months olds. Energy and protein requirements increase as the amount of muscle and adipose tissue increase in absolute terms for both tissues with gain in weight and/or age. These requirements have been measured and formulated as recommended intakes in the untrained horse (Table 5.11 to 5.14). There is a characteristic protein/energy relationship as the cost of protein synthesis is energy expensive and the intakes of energy and protein have an additive effect.

In the young horse in training work has the particular objective of developing muscle mass, structure (fibre type) and chemical composition to the detriment of adipose tissue to attain an optimum body composition and weight. These remain to be precisely established with respect to age, level and training program.

Daily weight gain combined with continued growth and the effects of training probably results in average gains of 250 to 350 g and 150 to 200 g at 18 to 24 and 24 to 36 months respectively if the nutrient concentration in the diet is high. It has been demonstrated in the young horse in training that the quantity of protein retained increases if the ration increases with work. This is the situation when the consumption of dry matter increases with age and work and protein retention improves with exercise. It seems reasonable to suggest for the young horse in training supplementary energy intake corresponding to the intensity appropriate for horses destined for racing or competitive sport should be available. Supplementary protein intake related to the energy in the diet and appropriate for age and the effect of exercise, perhaps similar to the production phase, may be required. Moreover, studies conducted by INRA and IFCE along with observations made by ENVA have established an optimum live weight for age model so that young horses grow rapidly but with a low risk of developing osteochondrosis. The young must not reach more than 72% of adult live weight by 12 months (Table 5.15).

5.3.2.6 Intake capacity: consumption

The feed intake tables also provide recommended dry matter intake values. These values indicate the quantity of feed that a young horse should consume to satisfy its needs or intake capacity (Chapter 1). It depends on: the horses' own characteristics: age, live weight, growth rate, body condition, past nutrition, the type of forage provided and the quantity of the concentrate feed offered.

In a general way, as the foal grows, satisfying its requirements becomes easier as its intake capacity increases while its capacity for growth diminishes. Two intake levels are proposed for each type of animal and each growth rate:

- The lowest is for diets with a high energy concentration: a high proportion of concentrate feed or (and) the use of forages with a very high energy content (example: corn silage at more than 30% DM or wilted grass silage at 60% DM);
- The highest is when the animals are given a diet high (80% or more) in average quality forage.

Forages are offered *ad libitum* in most case without regard to age of the animals. Intake capacity varies on average from 2.5 to 2.7 kg; 2.3 to 2.5 kg; and 2.0 to 2.3 kg per 100 kg live weight at 1, 2 and 3 years respectively.

The composition of the diet varies with the nature of the forage offered and the quantity of concentrate feed provided, and the inferred substitution rate (Tables 5.7 and 5.17). The nutritive concentration of the diet evolves with the age and desired growth. This is indicated in Chapter 1, Table 2.1.

5.4 Practical feeding

5.4.1 Before weaning

5.4.1.1 General scheme

Foals are born in most cases: sport horses, horses for leisure and draft horses, just before or after pasture becomes available, which is normally the first two weeks of April, except for race horses where it takes place earlier since they are destined to race as two year olds (Chapter 3, Figure 3.10).

In sport horse and leisure breeds foals are with their mothers mostly on pasture for 6 to 7 months with weaning occurring in early October (Chapter 3, Figure 3.11 and 3.12). They have a growth rate of 1,200 and 850 g/d, respectively, during the first 3 months and second 3 months following birth and an average of 900 to 1000 g/d from birth to weaning. Birth date has no significant effect on this growth as long as the dam is correctly fed and is in good body condition (Chapter 3). Foals are weaned at a weight of 225 to 275 kg at the age of 6 months. Foal growth depends upon the milk production of the mare and the quality of pasture from one month of age along with creep feed before weaning especially in foals destined for competition.

Draft horse foals are weaned in October at the age of 6 to 7 months. Colts are sold for fattening as well as the fillies that are not retained for replacements in the breeding herd.

5.4.1.2 Milk production

Normal milk production

During the first hours after birth it is necessary for the foal to obtain colostrum (by nursing if possible) in order to acquire immune protection and withstand thermal shock. Colostrum is rich in IgG_1 and IgG_2 as well as IgM and IgA in a small quantity volume representing 40% of milk proteins. It is also rich in lactose and lipids (Chapter 3). About 100 g of IgG is produced by the mare at each foaling. Colostrum is evaluated as good, average or poor based on the IgG content measured by Colotest. Colostrum is considered high if the content is greater than 60 g/l, average if between 60 and 40 g/l and poor if less than 40 g/l. The mare produces about 2.5 l of colostrum that the foal should drink as soon as possible after birth as the concentration of IgG decreases very rapidly after foaling (Figure 5.17) and the absorption of antibodies by the intestine ceases after 12 hours post-partum.

The Ig (in reality IgG) content in the foal's serum is a good criterion for evaluating the transfer of passive immunity. The foal is well protected if the concentration of immunoglobulin in the serum is 8 g/l 24 hours after birth, and if it is below 4 g/l remedial treatment must be considered (Figure 5.17). Causes of low Ig are multiple: premature birth and the associated insufficient time for the udder to concentrate immunoglobulin, premature leaking of milk from the udder before foaling, insufficient colostrum ingested, lack of maturity of the foal's intestinal mucosa preventing proper absorption, poor quality of the colostrum (low immunoglobulin content). Simple tests can evaluate the quality of

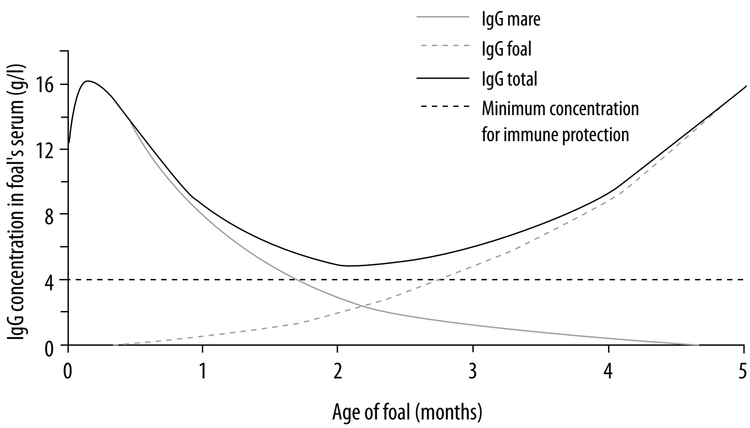

Figure 5.17. Changes in IgG concentration in the serum of during the first month after birth (adapted from Crawford and Perryman, 1990; Genin, 1990).

the colostrum as there is a close relationship between the concentration of IgG and specific gravity. It is then possible to use a colostrometer or a densitometer or the colotest popular in France. It is a refractometer that measures the sugar concentration in colostrum and which has been standardised to IgG content (Colotest®; Haras-Nationaux).

The level of immunoglobulin in colostrum can be stimulated naturally by not isolating the mare during the last month of pregnancy and thus exposing her to environmental antigens, or by artificially stimulating by a vaccination program over this same interval.

Determining foaling date is a good way of controlling the foal's acquisition of immunity. A test that measures the concentration of calcium in 1 ml of colostrum taken from the mare and diluted in 5 ml of ionized water will determine how close the mare is to foaling (Merckoquant® strips; Merck, Darmstadt, Germany).

In the event that the foal cannot drink colostrum of sufficient quality and quantity during the first 12 hours, it will be necessary to obtain colostrum from a colostrum bank in either frozen or lyophilized (at low temperature) form to give to the foal. The transfusion of the mare's serum to the foal is of limited effectiveness. Bovine colostrum cannot be used as bovine immunoglobulin is poorly absorbed by the foal and rapidly catabolised. In contrast, it has been recently shown that a good bovine seroclostrum given along with poor quality equine colostrum may be a solution to limiting problems of passive immunity transfer. It is possible to measure the quality of immunity transfer in foals measuring the foal's total serum proteins as this is closely associated with IgG when using the 'Foal' test at 8 hours after foaling (IDEXX Labroatories Europe B.V., Hoofdorp, the Netherlands and IDEXX Laboratories, Westbrook, ME, USA).

The 2 to 4 nursings per hour that are normal during the first week of life decrease to one nursing every 2 hours at 6 months (Figure 5.18).

During the first two months foal growth is due mainly to milk production by the mare which peaks at two months and to a favourable milk composition (Chapter 3) since pasture time is still limited (Figure 5.18). INRA has determined that on average 10.6 and 13.7 kg of milk per kg daily weight gain is required at 1 and 2 months of age respectively. In contrast grazing time increases and frequency of nursing decrease rapidly beyond the age of 2 months. Foal growth in sport and leisure breeds varies with the different grazing cycles, from 1,700 to 1,800 g/d during the 1st cycle to 1,100 to 1,200 g/d during the 4th cycle under pasturing conditions typical of naturally fertilised fields of Normandy and Limousin with a grazing load of 0.5 to 0.7 mare and foal per ha.

Milk replacer

If a foal is orphaned at birth, it will be necessary, in order to assure adequate immunity, that it consume within 12 hours colostrum preserved in a frozen state or provided by another mare that has just foaled. If this is not possible, it will be necessary to give subcutaneous injections of serum taken from the other mare. Next, adoption may be tried or the feeding of a milk replacer. In France there is currently an organisation (SOS foals) which provides for placing orphaned foals with fostering mares (for information see the French farmers' union or the National stud organisation so called IFCE web site: www.ifce.fr).

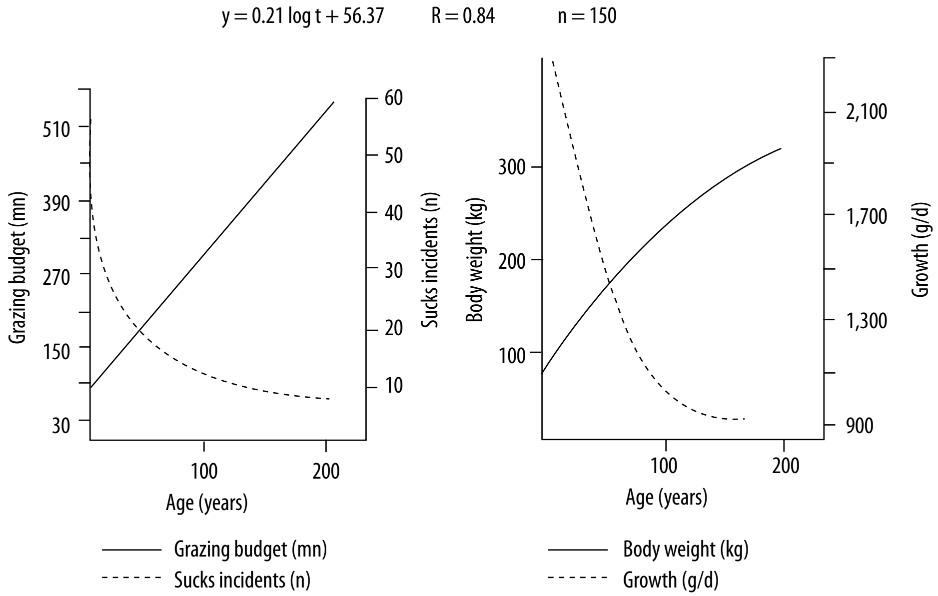

Figure 5.18. Variations with age, time of pasturing and live weight in number of nursing (Martin-Rosset *et al.*, 1978).

As a second alternative, the foal can nurse from a bottle for a few days then from a bucket with milk reconstituted from milk powder 'Special Foal' A substitute made from cow's milk or a calf milk replacer, adjusted in the following manner may also be fed:

- Prepare milk in which the dry matter content is 10%: for this mix ¾ litre of cow's milk with ¼ litre of water or dilute 100 g of calf milk replacer in one litre of water then,
- Add 30 g of glucose to both of these preparations and
- Adjust the concentrations of vitamins, calcium. and phosphorus and their ratio according to the formula for milk by adding a vitamin-mineral supplement.

The use of milk replacers requires careful hygiene and the following of the milk feeding guide in Table 5.18.

Weaning

Weaning usually takes place between the ages of 5 and 7 months and occurs abruptly. The progressive provision after weaning of hay, cereals and soybean meal in limited quantities and the presence of other foals or of one foal of the same age limits the stress of separation from the mother and provides optimal conditions for welfare from an ethological point of view (Chapter 15).

The provision of concentrate feed enriched with whey or milk powder through the first 2 months following weaning, fed as a complement to quality hay (12% crude protein minimum) especially if the supplementation is started before weaning will facilitate the transition and reduce the possible reduction in growth due to the stress of weaning.

Table 5.18. Feeding guide for milk replacers for light horse foals and draft foals.[a]

Age	Daily quantity of milk (l/foal/d)		Meals/day	Concentrate intake (kg DM/d)	
	Horse foals	Draft foals		Horse foals	Draft foals
1[b]	3.0	3.0	12		
2[b]	3.5	3.5	10		
3	4	4.0	10		
4	4.5	5.0	10		
5	5	6.0	10		
6	5.5	7.0	10		
7	6	8.0	9		
10	8.5	11.0	8	0.5	0.6
20	10	13.0	7	to	to
30	11	14.0	6	1.0	1.3
45	12	15.0	4	to	to
60	12	16.0	4	2.0	2.5
75	10	13.0	3	to	to
90	10	13.0	3	3.0	4.0
105	5	6.5	2	to	to
120	0	0	2	4.5	6.0

[a] Practical feeding recommendations: use a bottle fitted with a rubber nipple designed for lambs; sterilise the instruments after each feeding (boil in a container) for 3 to 4 days, after which they may be washed in hot water; Raise the milk temperature to about 30 °C; about the end of the 1st or 2nd week try feeding from a pail.

[b] In addition, during the first 1 to 2 days: 400 ml of colostrum in 3 feedings or 3 subcutaneous injections of 100 ml each of mare's serum.

5.4.1.3 Supplementation of the foal at weaning

Racing and sport breeds

Foals of racing breeds and to a lesser extent sport breeds are supplemented from 4 months of age because the mares' milk production and the quantity of forage eaten by the foal are insufficient to maintain a very high rate of growth (Table 5.19).

The composition of the concentrate feeds and the protein levels are crucial. Concentrate feeds based on milk products or milk powder and with a high protein content support much greater growth than feeds high in plant meals (Table 5.20).

Early weaning at 4.5 months of age accompanied by supplementation with concentrated feeds is often convenient or even necessary. The live weight reached at 7 months by foals normally weaned is only reduced 4%. Wither height is not different, but ossification in the early weaned foals is reduced (canon bone circumference, mineral density), but differences are eliminated by 7 months.

Table 5.19. Daily growth in foals supplemented or not between 2 and 6 months (adapted from Donabédian *et al.*, 2006).

Age (months)	Bodyweight gain (g/d)		Wither height (mm/d)	
	Not supplemented	Supplemented	Not supplemented	Supplemented
3-6	747	1,085	0.13	0.15
0-6	876	1,254	1.58	1.90

Table 5.20. Effect of source and protein content on growth of foals supplemented from 4 weeks to 11 weeks (adapted from Borton *et al.*, 1973).

Concentrate feed	CP (%)	Daily weight gain (g/d)
Soybean meal	14	600
Soybean meal	22	650
Milk powder	14	760
Milk powder	22	950

Foals can be supplemented before or after weaning with a concentrate feed based on milk products (milk powder or whey ultrafiltrate) with a minimum 18% crude protein content, 0.6% lysine, 0.5% threonine, 0.7% calcium, 0.4% phosphorus and 0.08% magnesium. The feed should contain diverse energy sources in addition to the milk products; limited amounts of cereals (≤30%), offset by the incorporation of fat to limit the risk of developing osteochondrosis during a key growth period. The feed is provided in the field in an adapted cattle feeder or in a box stall at night.

Draft breeds

Nursing foals are rarely supplemented as they are destined for sale as thin weanlings for fattening (Chapter 7). Similarly for fillies destined to be replacements, who will not be supplemented for economic reasons.

5.4.2 After weaning

5.4.2.1 Breed and type of production strategies

Racing, sport and leisure horses

Two types of management are envisioned depending on production objectives. Considering production for early development of race horses, foals will be supplemented with 1 or 2 kg of feed. However, it is recognised that this period of rapid growth, which is a major risk factor, is when osteochondrosis lesions are likely to appear. For this reason it is much better if live weight at weaning is not greater than 50% of adult live weight. The average weight of the mare and the stallion will provide an estimate of adult live weight (Table 5.15). Such an estimate will also give and objective basis for guiding growth of the young horse. Wither height measured at 2 and 6 months of age should also not be more than 72 and 84%, respectively, of adult height, estimated as for weight, to control the risk.

Sport horses, even destined for competition and, fortunately, horses for leisure purposes; do not justify feeding significant amounts of concentrate feeds if pasture is of sufficient quality. In contrast mineral supplementation is necessary if the pasture forage is not well balanced in minerals and micronutrients (Chapters 12 and 16).

Draft horse breeds raised for replacement

To produce replacement fillies for the breeding herd (fillies bred at 3 years) and future breeding stallions, the accepted strategy is to produce optimal growth from the animal production and economics points of view. Feeding is restricted during the winter to make maximum use of pasture forage in summer and exploit the capacity for compensatory growth.

However, fillies bred at 2 years of age must be given a substantial amount of feed corresponding to the optimum levels proposed in Table 5.16 and 5.17. These are intakes designed to reach 85% of adult live weight before breeding. Draft horse replacement fillies that are most often managed to make extensive use of grazing resources should also be supplemented with minerals and micronutrients.

5.4.2.2 Feeding programs

Racing, sport and leisure horses

Young light horses can be fed using the extremely varied feeding programs tested by IFCE and INRA (Table 5.21 to 5.23). When producing light horse breeds for early competition recommendations are to use hay of very high quality (0.60-0.65 UFC/kg and 50-60 g MADC/kg) provided free choice or wilted silage at 50-60% dry matter. This should be supplemented with grains and soybean meal in amounts that take into account the age of the animal and the nutritional value of the forage.

The production of light horses for more delayed development allows the young horse to be fed differently during the winter: either with a diet based of forages of limited nutritional value (0.50-0.55 UFC and 40-50 g MADCP/kg) but fed free choice (delayed harvest, native hay or a mix of straw and hay), grass or corn silage with a dry matter content of 30%, or with forages of high nutritional value but in limited quantities (early cut hay, alfalfa hay, second cut fed with a straw based ration offered free choice, fresh cut grass silage or whole plant corn silage with a dry matter content of at least 35%, or wilted silage at 60% dry matter).

In any case, the diets should be supplemented in energy with grains and protein with meals (soybean or peanut) or legume seeds (lupine sweet, faba bean). Provision of minerals, trace elements and vitamins must also complement fed or grazed components.

Table 5.21. Feeding of growing light horses during the 1st winter: 6-12 months (500 kg adult weight). Average live weight during this period: 280 kg (adapted from Bigot *et al.*, 1987; Trillaud-Geyl and Martin-Rosset, 2005).

Diet formulation	Wilted grass silage		Corn silage		Hay	
Diet composition (%)						
Forage	60-70	75-85	65-75	80-85	65-75	85-90
Concentrate feed	35-40	20-25	25-35	15-20	25-35	15-20
Quantity ingested (kg/DM)						
Total	6.5-7.0	6.5-7.0	6.0-6.5	5.5-6.0	7.0-8.0	7.0-7.5
Growth (g/d)						
Optimal	500-700		700-800		400-500	
Moderate		400-500		600-500		250-300
Energy density of the ration						
UFC/kg DM	0.81	0.67	0.88	0.78	0.73	0.62

Table 5.22. Feeding of growing light horses during the 2nd winter: 18-24 months (500 kg adult weight). Average live weight during this period: 429 kg (adapted from Bigot *et al.*, 1987; Trillaud-Geyl and Martin-Rosset, 2005).

Diet formulation	Wilted grass silage		Corn silage		Hay	
Diet composition (%)						
Forage	75-80	85-90	80-85	85 -90	70-75	80-85
Concentrate feed	20-25	10-15	15-20	10-15	25-30	10-15
Quantity ingested (kg/DM)						
Total	10.0-11.0	9.5-10.5	8.0-9.0	7.5-8.5	9.5-10.5	9.0-10.0
Growth (g/d)						
Optimal	400-500		500-700		250-350	
Moderate		200-300		300-400		100-200
Energy density of the ration						
UFC/kg DM	0.65	0.60	0.80	0.75	0.68	0.63

Draft horses

Winter feeding can be based on hay (with or without straw) or silage (grass, not wilted or whole plant corn) with, depending on the forage and the age of the animals, a supplement restricted to 0.5 or 3 kg per day, composed of grains (barley, corn), sunflower, rapeseed meal, (or beans or lupines), and the necessary minerals and vitamins. Ration quantities are guided by recommendations developed for moderate growth (Table 5.16 and 5.17).

Table 5.23. Feeding of growing light horses during 3rd winter: 24-30 months (500 kg adult weight). Average live weight during this period: 484 kg (adapted from Bigot *et al.*, 1987; Trillaud-Geyl and Martin-Rosset, 2005).

Diet formulation	Wilted grass silage		Corn silage		Hay	
Diet composition (%)						
Forage	80-85	85-90	80-85	85-90	75-80	85-90
Concentrate feed	15-20	10-15	15-20	10-15	20-25	10-15
Quantity ingested (kg/DM)						
Total	11.0-12.0	10.5-11.5	9.0-10.5	8.5-10.0	11.0-12.0	10.5-12.5
Growth (g/d)						
Optimal	200-300		300-00		50-100	
Moderate		100-200		200-300		0-50
Energy density of the ration						
UFC/kg DM	0.57	0.50	0.65	0.60	0.57	0.50

5.4.2.3 General comments on feeding

Following the stress of weaning, where the foal has obtained a palatable and adequate diet, it is possible to feed the foal in a liberal, moderate or restricted manner.

Any quantitative or qualitative change in diet must be made gradually, as in the replacement of hay by straw, hay by silage, increase in quantity of concentrate, or transition from grazing to preserved forages. This transition is very important if the animals are to consume silage. Following a grazing period it is advisable to provide hay for 2 to 3 weeks then gradually transition to silage over the course of 2 to 3 weeks.

Every time the animal is under stress (weaning, castration, changing location, separation from companions, breaking, accident or illness, etc.) the feed should be adjusted, as much from a qualitative as from a quantitative view, in order to minimise growth problems. The foal should also be regularly dewormed (Chapter 2).

5.4.2.4 Pasture

The young horse is fed on pasture grass for a large part of the year: from April to October depending on location. The young horse may graze alone or in combination or in alternating with cattle on natural grasslands managed as described in Chapter 10. The young horse is able to enhance the value of the grassland as much as when older. The intake capacity for grass by the young horse increases considerably from 12 to 18 months (by 20-25%) because of the development of the digestive tract, particularly the large intestine where most of the forage is digested and again from 24 to 30 months (10-15%). The horse truly develops into an herbivore.

Meeting requirements

The young horse of the race horse breeds is raised in the grasslands areas of the humid plains. It achieves a continuous high rate of growth in order to be ready to race as a two year old. The young horse is only pastured during the daytime and at night is housed in a stall both for security reasons and to receive supplemental feed. The live weight gain achieved at pasture only represents 50% of the total live weight gain between weaning and 2 years of age.

In sport horse and leisure horse breeds the young horse is raised on grasslands areas of both humid and drier regions. Young horses destined for high competition levels are managed similarly to those of the race horse breeds. Live weight gains while grazing represent about 60% of the total live weight gain between weaning and 4 years of age. Other sport horses and those destined for leisure activities are managed according to a model of discontinuous growth. Live weight gain while grazing represents 65% of total live weight gain between weaning and 4 years of age. The young horse undergoes a compensatory summer growth that is at least the equal of or much superior to moderate winter growth depending upon age and grazing conditions. There is a relationship between the level of summer growth (y) and winter growth (x) that varies with age:

For animals 12 to 18 months: $Y = 785.65 - 0.302X$ $R=0.627$

For animals 24 to 30 months: $Y= 439.28 - 0.404X$ $R=0.629$

For animals 36 to 42 months: $Y = 658.9 - 0.603X$ $R=0.756$

Draft horse fillies are managed to produce a discontinuous growth model. Live weight gain while grazing depends in part making the most of spring and summer conditions for that horse raised in the mountains or the hilly plateaus and accounts for 65 to 70% of total live weight gain between weaning and 3 years.

Supplements

The feeding of concentrates to complement hay in box stalls in the evening is a current practice in future equine athlete management. The amounts offered should not exceed 1 to 3 kg depending on age and grazing conditions in order not to pass the risk threshold for the development of osteoarticular pathologies that are discussed in Sections 5.1.6.3 and 5.3.2.4 and 5.4.2.1.

Supplementation while on pasture with mineral supplements (minerals and microelements) is necessary no matter what type of horse is produced since no pasture forage will meet all requirements, especially in minerals (Chapters 12 and 16). For young equine athletes supplementation is guaranteed with the concentrate fed in boxstalls in the evenings. In contrast supplementation of other types of horses is provided by using licking blocks enriched with minerals and microelements made freely available in the field and monitored for level of consumption (50 to 100g/d/horse depending on the guidance on the label).

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References quoted through the text are only listed; for other references which are supporting the chapter, see 'Further reading'.

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Chapter 6. The exercising horse

William Martin-Rosset and Yves Bonnaire

There are about 120,000 to 150,000 working horses in France. About 15% are racing on race tracks, 85% are used for sports and leisure and a low percentage are devoted to agricultural work and mainly forestry. We could expect that such figures are more or less similar in most industrialised countries.

Nutrient requirements, especially energy, are of a very different type and importance because the type of effort, intensity, duration and repetition vary widely. The work occurs in very different environmental conditions and is more or less variable in time as well.

The end-users of these horses have very contrasting objectives. For horses devoted to competition, the challenge is to maximise the biology and efficiency of the organism, e.g. sport medicine and nutrient metabolism to reach the desired performance assuming other factors are well managed. These horses are mainly ridden by professionals who are advised by specialised officers (veterinarian, etc.). For horses that are used for leisure, e.g. instruction in riding school, or hacking by amateurs, the aims are different. For school horses nutrient allowances should be optimised to permit the horses to be used on a regular schedule at a limited cost. For amateurs' horses (very often in private facilities), the nutrient allowances should be simple, low cost and ensure the horse's well-being. Those horses are ridden by amateurs with various skill levels.

In this chapter, the main fundamentals of physiology and metabolism of exercise are described to better understand the nutritional requirements and the recommended feed allowances.

6.1 Physiological and metabolic consequences of exercise

Exercise affects biomechanics, physiology and metabolism of body, organs and tissues.

6.1.1 Main physiological phenomena

6.1.1.1 Cardio-respiratory frequency

At rest (VO_2 is 3% of VO_{2max}), the respiratory frequency ranges within 15 to 5 respirations/min while cardiac frequency is 35 beats/min. At work the respiratory and cardiac frequencies rise as gait and velocity increase respectively to between 60-65 and 70-75 at a walk (VO_2 14% or velocity range 40-100 m/min) to 100 and 150 at an average gallop and 120 and 240 at the fastest gallop (VO_2 is 100% VO_{2max} or velocity 800 m/min). The frequencies remain relatively high during the recovery period until resting levels are attained (VO_2 is 20% VO_{2max}) after 5 min: 90-110 and 80-90 for respiratory and cardiac frequencies, respectively. Respiratory and cardiac frequencies increase linearly with velocity then plateau at 150 and 240, respectively (Figure 6.1A).

The inspired air volume ranges, on average, from 3 to 70 l/s when the horse moves from rest to a maximum gallop respectively. The air volume is still 20-25 l/s during recovery period. Those

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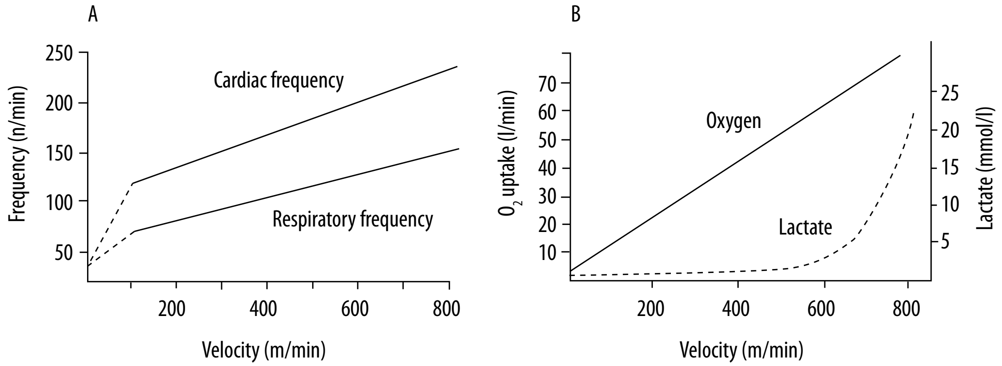

Figure 6.1. Influence of velocity on (A) respiratory and cardiac frequencies (adapted from Wilson *et al.*, 1983), and (B) oxygen uptake and blood lactate concentration (adapted from Hornicke *et al.*, 1983).

frequencies and volumes, included the recovery period, vary with the intensity, the duration of exercise, the horse's own abilities, and training and environmental conditions. They have been intensively studied

6.1.1.2 Oxygen uptake

The oxygen uptake extracted from inspired air is necessary to permit an energy expenditure corresponding to the effort. Oxygen uptake in the early stage increases linearly with velocity (Figure 6.1B), from rest until a 600 m/min gallop because metabolism remains aerobic (VO_2 max. 60%). Beyond this velocity, the rise of oxygen uptake is curvilinear because anaerobic metabolism increases (maximum velocity 800 m/min – VO_{2max} 100%). Oxygen uptake can rise from 3 ml/min/kg bodyweight at rest to 125 ml/min/kg bodyweight at submaximal exercise (700 m/min). Oxygen uptake also varies with the load that is transported by the horse (rider bodyweight, tack, etc.) with the slope of the track, and with the duration combined with intensity of exercise.

VO_{2max} is the maximal oxygen uptake possible regardless of the exercise load. It has been measured at a maximum gallop velocity of 800 m/min in Thoroughbreds. The increase of velocity at the highest intensities is possible due to anaerobic metabolism. No relationship between VO_{2max} and performance has been demonstrated in horse.

Oxygen uptake can be insufficient in respect to demand to oxidise the energy substrates in two situations. At the beginning of exercise, the horse can anticipate the energy expenditure, but oxygen uptake will be insufficient to meet this demand that is short but instantaneous. It is a so-called transitory deficit. Following supramaximal exercise, energy expenditure will continue for some time, but oxygen uptake remains insufficient to satisfy the heavy demand resulting in what is termed an oxygen debt (Figure 6.2). This accumulated difference ranges from 30 to 128 ml/kg bodyweight. During this time the horse's metabolism is anaerobic. The accumulated difference is not correlated with VO_{2max}. It has not yet been demonstrated that this is related to the horse's performance.

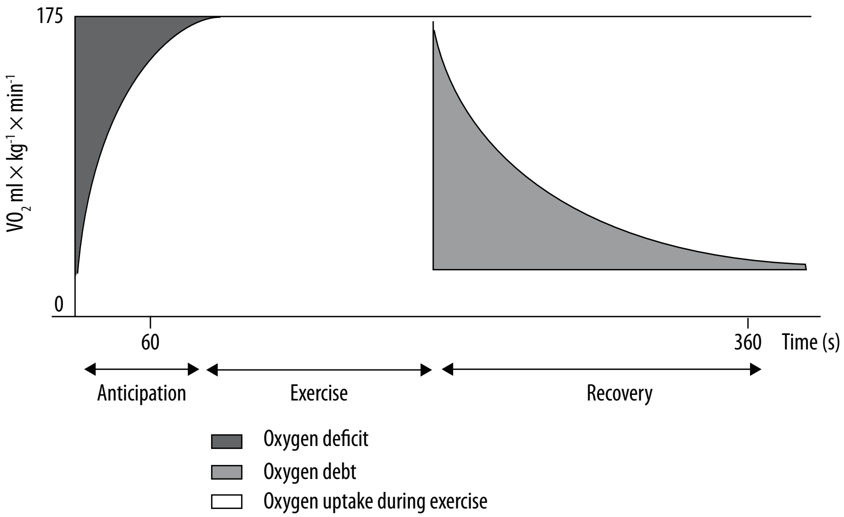

Figure 6.2. Oxygen uptake kinetics during the periods of exercise (adapted from Eaton, 1994).

6.1.2 Metabolism of energy sources

6.1.2.1 In muscle tissue

Locomotion is implemented by skeletal muscles, which represent 45 to 55% of horse bodyweight. The skeletal muscles are structured as fibres whose contractile and metabolic properties are specific to the type of exercise (Table 6.1). The tensing ability depends on the type of myosin and of myosin-ATPase present in the fibres. Moreover, the fibres contract more quickly as their ability to use oxygen,

Table 6.1. Characteristics of the different types of muscular fibres in the horse (adapted from Snow, 1983).

Characteristics	Fibre types[1]		
	I	IIA	IIB
Velocity of contraction	slow	rapid	rapid
Activity of myosin ATPase	low	high	high
Number of mitochondria	+++	++	+
Oxidative capacity	high	intermediate to high	intermediate to low
Lipid content	high	intermediate	low
Glucolytic capacity	low	high	high
Glycogen content	intermediate	high	high
Fatigability	low	intermediate	intermediate to high

[1] I or ST = slow twitch; IIA or FTH = fast twitch high oxidative; IIB or FT = fast twitch.

or oxidative capacity, decreases. Glycogen and lipid contents are high and low respectively, and capillary density is low in the very fast type IIB fibres. Conversely, type I fibres contract slowly and their ability to use oxygen is high. Their lipid content and capillary density are high. Type IIA fibres are intermediate.

The lipid (triglycerides) content of muscles is much higher in endurance horses than in Thoroughbreds or Trotters because they primarily use oxidative metabolism of lipids via fibre types I and IIA during extended exercise (Table 6.2). Conversely, glycogen content is higher in Thoroughbreds and Trotters, which primarily use glucose via the aerobic/anaerobic metabolism of types I and IIA fibres. Lipids are also metabolised as the duration of exercise rises (long sprint) (Table 6.2). Jumper horses recruit mainly IIB fibres to use primarily glucose and glycogen via anaerobic pathways.

Muscular fibre's, and especially the numerous mitochondria they contain in greater or lesser amounts depending on fibres type, are the sites of free energy production as ATP (adenosine triphosphate) from energy substrates that they accumulate or extract in the blood. Fibres I and IIA are activated in light and moderate exercise. The energy is produced from the catabolism of long chain fatty acids and from circulating glucose and glycogen (Chapter 1, Figure 1.2).

As velocity increases, IIB fibres are recruited in addition to fibres I and IIA. Energy is produced by the conversion of glucose to lactate (or glycolysis) because anaerobic metabolism plays an increasing role (Figure 6.1B). At the highest velocities, anaerobic metabolism of glucose and creatinine phosphate is added to aerobic metabolism which, although at maximum, cannot cope with the elevation of energy expenditure at such speeds. In some extreme conditions, energy production is through anaerobic metabolism, mainly of pyruvate and alanine, and to a lesser extent branched-chain amino acids such leucine and isoleucine, whereas glutamate decreases with the increase of alanine supplied by of transamination of pyruvate. Hence, some protein catabolism may occur at the highest intensities.

Three metabolic systems are active more or less simultaneously in the mitochondria according to the type and duration of exercise. In all cases, the production of free energy, ATP, is required in the mitochondria of muscle cells by successive biochemical reactions which differ depending on whether the mechanism is aerobic or anaerobic (Figure 6.3).

Table 6.2. Fibres composition, glycogen and triglycerides content of gluteus muscle in different breeds (from Essen-Gustavsson, 2008).

Horse breeds	Muscular fibres			Energy reserves	
	Type I (%)	Type IIA (%)	Type IIB (%)	Glycogen[1] (mmol/kg)	Triglycerides[1] (mmol/kg)
Thoroughbred (n=10)	15±5	56±11	29±10	570±39	15±9
Trotters (n=23)	26±5	54±9	20±9	685±122	30±18
Endurance horses (n=21)	16±7	41±7	43±8	519±86	58±37

[1] Dry weight.

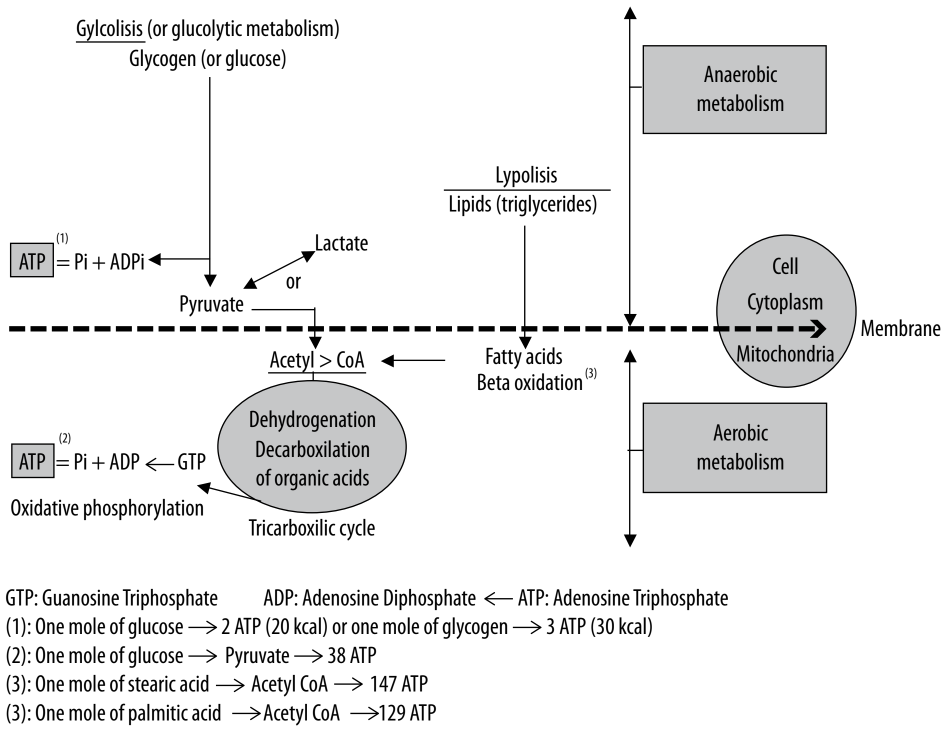

Figure 6.3. Simplified chart of production of free energy as ATP via aerobic or anaerobic pathways: glycolysis, oxidation of fatty acids and Krebs cycle (or tricarboxylic cycle) in the cell.

The aerobic system is active during exercise of moderate intensity of variable duration. The pyruvate delivered by the anaerobic metabolism of glucose and glycogen is transformed via the tricarboxylic acid cycle (or TCA: Krebs cycle) and oxidative phosphorylation into ATP. The fatty acids delivered by lipolysis of triglycerides are transformed via β-oxidation and the TCA into free energy (ATP). The aerobic system is slow but very efficient as one mole of glucose produces 38 ATP while a mole of fatty acids, for example stearic acid, 147 ATP. In other words 6.32 ATP/mole oxygen are produced per mole of glucose and 5.65 ATP/mole oxygen per mole of fatty acids. But the utilisation of lipids depends on the availability of carbohydrates (Figure 6.3 and Chapter 1, Figure 1.2). In extreme cases, the amino acids delivered by the degradation of proteins can be used to supply glucose after deamination (loss of amino group NH_2), that is gluconeogenesis.

The anaerobic system is mainly involved during short and intense exercise or at the end of long endurance competition. Hence, free energy, ATP, is delivered without oxygen only from glucose and glycogen via a mechanism called glycolysis. A mole of glucose produces only 2 ATP whereas a mole of glycogen contributes 3 ATP. This system is efficient and fast but is very brief (few minutes). A by-product is lactate which that gives rise to muscular acidosis.

The creatine-phosphate system focuses on the very early period of exercise (10-15 seconds) whatever the exercise. It ends when the energy reserves of creatine-phosphate are exhausted. This anaerobic mechanism produces ATP.

6.1.2.2 In the organism

At rest

Horse energy expenditure generated from the different organs and tissues, the turn-over of cells and tissue structures especially those of protein, ion transportation, etc. is continuous. To cover these expenditures the horse uses long chain fatty acids, glucose, acetate and sometimes amino acids and ketone bodies (Chapter 1, Figure 1.2). These energy substrates can be used immediately during the periods when they are absorbed after a meal. In the interval between meals the horse uses lipids and glycogen reserves.

Lipids represent by far the most important energy reserve in the organism (Chapter 2). In a horse of 500 kg bodyweight, average body condition score (score: 3) fat tissues can account for 6 to 8% of bodyweight, e.g. 30 to 40 kg. During periods of energy deficit, triglycerides issuing from adipose tissues are hydrolysed into glycerol and non-esterified fatty acids (NEFA), which circulate in the blood. Those NEFA are captured by the muscles, which use them directly, and by the liver which releases them again into the circulation as lipoprotein. Plasmatic NEFA concentration shows the variation of energy balance during day and night periods: it decreases during the ingestion and absorption period and then increases during the fasting period. Plasma acetate and β-hydroxybutyrate concentrations follow the same evolution.

Glycogen reserves are located in the muscles and liver, which represent 50 and 1%, respectively, of bodyweight in a horse of 500 kg bodyweight. Glycogen content of muscular mass ranges within 1.5 to 2.5% of muscle weight in the horse at rest. Glycogen reserves might range from 4.5 and 5.5 kg. They rise with training but less than in humans.

Post-prandial glycaemia is maximal 90-120 min after a meal then it returns to pre-prandial concentrations within 5-6 h. Insulin follows the same pattern. The variation depends on the type of diet (hay ± concentrate), the type of cereal grains and method of distribution (hay before or after concentrate). Circulating glucose can be quickly used to satisfy energy expenditure or stored in the liver, muscle tissue and/or adipose tissues as glycogen or lipids respectively. Lipids are stored as fatty acids then triglycerides according to the amount of absorbed glucose and the immediate energy requirements that must be met. Amino acid concentration is maximal between 2 to 5 h after meal according to the type of diet and method of distribution.

Feed lipids (triglycerides) are also absorbed. They are transported in the blood by the chylomicrons towards the sites where they are metabolised or stored. Volatile fatty acids that are produced and absorbed in the large intestine are used either to meet energy requirements or to contribute to the synthesis of glucose (Glycogenesis) or lipids (lipogenesis) in the liver (Chapter 1, Figure 1.10).

Insulin is a principal player involved in regulation and utilisation of these nutrients: catabolism, capture by tissue, or synthesis of reserves from absorbed nutrients to maintain steady glycaemia.

Glycaemia decreases between two meals. Glucose is the essential energy substrate for the central nervous system and erythrocytes, leucocytes, medullosurrenal gland, and retina, whereas the requirements of muscles, liver, etc., can be met by NEFA. To meet essential glucose expenditures and maintain glycaemia, the liver hydrolyses glycogen reserves and synthesises glucose from amino acids (alanine and glutamine) available from the catabolism of muscle protein, from glycerol supplied by hydrolysis of triglycerides as well as carbon substrates (lactate ad pyruvate) from glucose catabolism in muscle, thus ensuring a true recycling (neoglucogeneis) (Chapter 1, Figure 1.10).

Light to moderate exercise

When the horse undergoes short term exercise (30 min) at a moderate intensity (ex. trot 200 m/min) the daily energy expenditure is satisfied by oxidation of plasmatic long chain fatty acids (NEFA). The fatty acids are supplied by circulating plasma and intra-muscular triglycerides (Chapter 1, Figure 1.2).

When the intensity of exercise rises (e.g. trot 300 m/min or VO_{2max} 30-35%), the increase in energy expenditure by the horse is covered by the accelerated catabolism of circulating glucose, intramuscular glycogen and long chain fatty acids. All these substrates are totally oxidised. The oxidation of plasma glucose meets 6-12% of the energy expenditure. The contribution of lipids rises as indicated by the decrease in the respiratory quotient ($RQ = CO_2/O_2$), which decreases from 0, 95 to 0, 88. Initial NEFA concentration decreases in plasma as a result of muscle extraction under the effect of noradrenalin, then it increases as body lipids are mobilised and the turn-over rate of NEFA rises by 50%. The plasma concentration of glucose decreases, whereas that of glycerol increases but that of lactate is not changed.

Under moderate exercise as during an endurance ride at 200-300 m/min for 40 to 160 km, metabolism is fundamentally aerobic. The contribution of body lipids can be multiplied 10 times, glycogen reserves in liver and muscle decrease gradually. Glycaemia is diminished by 25 to 65% in reference to pre-race values according to the difficulty of the race or ride but with great individual variability between horses. NEFA concentration in plasma is increased 6-15 times and glycerol increases dramatically. Lactate, β-hydroxybutyrate and acetoacetate concentrations increase slightly because glucose and NEFA are totally oxidised and ketone bodies are only minimally involved. The mobilisation of energy substrates is due to the decrease of insulin secretion and the increase of catecholamines, cortisol and glucagon. These latter two stimulate gluconeogenesis.

It should be stressed that, even during moderate exercise at 30-60% VO_{2max}, glucose is required (Figure 6.3) to satisfy the energy expended however, energy supplied from NEFA predominates whatever the duration of exercise as shown by the evolution of the respiratory quotient.

Intense exercise

Muscle glycogen contribution increases rapidly and becomes predominant as the intensity of exercise increases (VO_{2max} >80%). Mobilisation of muscle glycogen varies from 30 to 100% depending on the duration of exercise. In the early stage of exercise glucose is supplied by the glycogenolysis of hepatic glycogen. Glucose can be supplied by gluconeogenesis if the precursors are available (glycerol, lactate and alanine) when exercise is prolonged. In the ultimate phase, the liver is not capable of supplying glucose, glycaemia decreases and the horse reaches the fatigue threshold. The lactate, which accumulates in muscles and blood results in metabolic acidosis promoting fatigue.

Blood lactate concentration is a good criterion of the involvement and the importance of anaerobic metabolism. Lactate concentration remains low if the velocity does not exceed a threshold of 300-400 m/min in the Trotter which corresponds to 150-160 heart beats and VO2max of 50-60%. This threshold is likely higher in race horse. Furthermore, lactate concentration rises exponentially with velocity at the gallop or trot (Figure 6.1B). At the same velocity, blood lactate concentration is much higher in untrained horses.

The importance of proteins in meeting requirements and their metabolism during exercise remains very controversial. In extreme exercise, protein could account for 5 to 15% of the energy used. Plasma alanine concentration rises during moderate exercise while plasma urea concentration increases during endurance exercise.

The blood modifications at the end of galloping races of 1000 to 2,400 m are spectacular. Lactate accumulation is about 25 mmole/l and results in a fall of pH from 7.49 to 7.00 and of alkaline reserves. Glycaemia increases by 60 to 90%, and glycerol concentration is 40 to 50 times higher which is the result of stimulation of the hydrolysis of hepatic glycogen and lipids of adipose tissue. These modifications are greater than those observed at the end of trotting races. Exercise at such intensity can last only a few minutes.

Long endurance competitions (80 to 160 km) ridden at velocities higher than 16-18 km/h leads to a very high elevation of NEFA plasma concentration, 1,689 mmole/l, which shows a very important mobilisation of body lipids. Such an elevation can be only possible if the initial body condition score is optimal (score ≥3), otherwise the probability of the horse performing well is low. In addition, a velocity as high in the second part of the race as in the first leads to the involvement of fibres with anaerobic metabolism, particularly if the horses are well trained. Blood lactate rises dramatically.

In summary, body lipids are the essential fuel of working horses, and are oxidised by fibres I and IIA up to a velocity 400 m/min in the case of trotting races and likely to 500-600 m/min in flat racing. The anaerobic threshold would correspond to 50-60% VO_{2max}. Beyond this point, the catabolism of glucose rises gradually (Figure 6.3). However, the utilisation of these two energy sources on both sides of the anaerobic threshold does not respond to an all or nothing law. Carbohydrates are always used in variable amounts throughout the exercise depending on duration and intensity because they are essential in the catabolism of lipids to produce ATP. We used to say: 'the lipids are burnt in the flame of carbohydrates'.

The recovery

After the end of exercise, metabolism remains high and oxygen uptake is elevated. This period is divided in two phases. The first is a primary slow phase called 'lactic' because it corresponds to the oxidation of lactic acid that has accumulated. The second is a fast phase called 'alactic' which consists of the resynthesis of phosphagens that are rich in energy. The duration of the slow phase is 10 to 20 times longer than the fast phase. The recovery period also includes the rephosphorylation of creatine and adenosine diphosphate (ADP), which are essential to metabolism.

Influence of training and feeding

The aim of training horses in sprint racing is to raise both their acceleration ability and fatigue threshold linked to lactate accumulation in muscles. This is accomplished by improving muscle fibre hypertrophy and elevating the anaerobic threshold. The result of the latter is a decrease of lactatemia for the same effort. This adaptation is achieved by elevating the oxygen supply to muscles (vascularisation), in increasing NEFA supply to muscles that are involved, in glycogen and NEFA utilisation, and finally the activity of some enzymes of glycolysis and oxidative metabolism.

The aim of training for endurance riding is to increase first the resistance of horse to fatigue then velocity. Training should both increase NEFA utilisation to spare glycogen and delay fatigue occurrence while elevating the anaerobic threshold which delays lactate accumulation.

The diet of horse undergoing strenuous exercise should contain cereals grains and other concentrates to supplement forages in order to cover energy expenditure in a limited volume and provide precursors of glucose. Assuming that quantitative energy requirement are met, are there energy sources that are more adapted and capable of improving horse performance?

Oats are the main cereal grain fed by trainers to race horses as they are wary of maize. In fact, no significant difference of performance has been observed in horses fed the same amount of energy (UFC/kg DM) as maize or oats. The detrimental effect observed by professionals is likely due to diet formulation error. At the same volume maize provides 50% more energy (UFC) than oats or, conversely, one kg fresh maize corresponds to 1.3 kg fresh oats because the density per litre of maize and oats is different (Chapter 9).

Can the glycogen reserve be increased in horses as in humans by feeding a high carbohydrate diet during several days prior to competition? Glycogen content of muscles in horses has changed in the same direction as starch content of rations but to a more limited extent than in humans. In horses the change has been between 1.9 to 2.5% comparing diets without starch, traditional diets with 50% oats to enriched diets containing 35% maize starch.

Most of trials that have been carried out combining a prior depletion period of glycogen reserves using fatiguing exercises in horses fed a low carbohydrate diet, followed by a repletion period during which a carbohydrate rich diet is fed, did not show any overcompensation effect on glycogenic reserves as in humans.

The utilisation of fat in horse diets has occurred due to the good results obtained in man. Net energy content per kg DM of fat is, on average, 2.5 times greater than that of cereal grains. The enrichment of diets containing 7 to 10% oil (maize, soya, etc.) promotes a sparing effect on the utilisation of muscle glycogen because glycaemia is higher after exercise and the respiratory quotient is also decreased as shown in early studies (Figure 6.4). More recent studies do not confirm these conclusions, however. Lipid supplementation does not increase triglycerides in muscles. Glycogen content of muscles and glycaemia, following submaximal exercise, decreases in horses supplemented with lipids as in horses supplemented with carbohydrates. The mechanisms which drive these phenomena are still to be discovered.

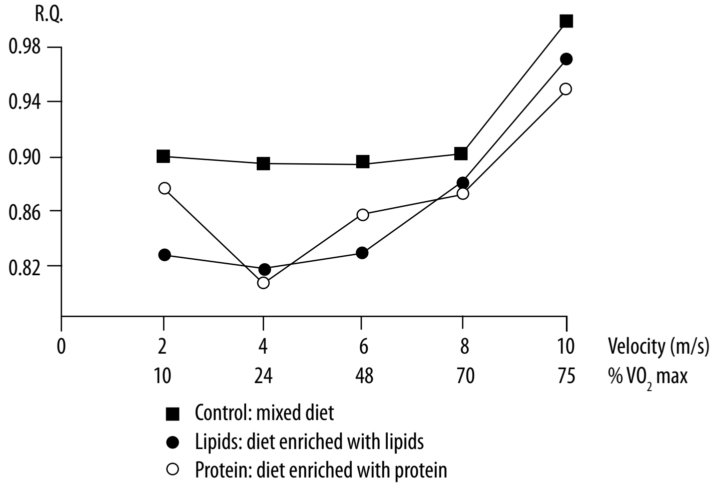

Figure 6.4. Effects of feeding diet on the metabolic utilisation of energy measured by the respiratory quotient (RQ) (adapted from Pagan *et al.*, 1987).

Race horses are generally fed diets containing excess crude protein in respect to their requirements due to high crude protein contents of diet ingredients such as the high quality cereal grains and forages that are fed. A survey of 563 performances of 171 horses has observed that performance time is decreased by 1 to 3 seconds for racing distances of 1,200 and 1,700 m respectively, when this excess is 1000 g of crude protein over recommended intake (×2.5) because cardio-respiratory frequencies and sweating in horses are elevated. In addition, if protein is substituted for part of the carbohydrate, the glycogen concentration in muscles is lower before exercise and decreases more during exercise.

6.1.3 Mineral and electrolytic metabolism

During exercise the variation in increased heat production can range from 10 and 60 times that produced at rest depending on exercise intensity. It represents on average 75% of heat that is produced by the organism (Chapter 1, Figure 1.11). Performance can be limited if this excess heat is not eliminated especially during prolonged exercise. Sweat is the main pathway to dispense with this excess heat production. Sweat production in horse ranges from 2 to 15 l/hour according to gait and velocity, the distance and the duration of exercise and environmental conditions (temperature and humidity). That leads to a total loss of 20 to 50 l, i.e. 4 to 10% of bodyweight (Table 6.3). In extreme condition, the loss can be the equivalent of total blood volume.

Sweating leads to compulsory losses of minerals (Ca-P-Mg) and electrolytes (K-Cl). They are involved because they are present in ionised form, positive (cations) or negative (anions), in intra or extra cellular liquids and dissolved in blood. The concentrations in plasma and sweat are quite different (Table 6.4). The concentration of each of them is regulated by different mechanisms. The loss of minerals and electrolytes are compulsory during exercise and they cannot be anticipated as there are no body reserves. These losses contribute partially to performance because they promote the occurrence of fatigue. The losses should be quickly restored after exercise to prevent disorders for

Table 6.3. Bodyweight losses linked to sweating during different types of exercise (Valle and Bergero, 2008).

Type of exercise	Loss bodyweight (kg)	Authors
Thoroughbred at gallop	4.5-7.3	Lewis, 1995
Trotter (race 1,600 m)	5.5-15.0	Lewis, 1995
Horse hunting (3 h)	11-45	Lewis, 1995
Three days event: rapider phase and of endurance	10-21	White, 1998
Endurance		
80 km	30-50	Lewis, 1995
32 km (hot and humid)	15-25	Bergero *et al.*, 2001

Table 6.4. Electrolytes concentration of plasma and sweat in horse (g/l) (adapted from Lewis, 1995).

	Chlorine	Sodium	Potassium	Calcium	Magnesium
Plasma	3.5	3.2	0.16	0.12	0.024
Sweat	5.9-6.2	3.0-3.7	1.2-2.0	0.08-0.24	0.024-0.2

these ions are involved in numerous mechanisms: osmosis between compartments, neuromuscular transmission, acid-alkaline equilibrium and pH.

Sodium is a major cation of intracellular compartments. Sodium promotes body water flux during its own extracellular transport as it assists the development of osmotic gradients due to the production of required energy by the Na/K – ATPase pump. Sodium is also involved in the transmission of nerve impulses.

Chlorine is an anion necessary for respiration. It contributes, with potassium, to the exchange of oxygen and carbon dioxide through oxyhemoglobin via the carbonate of tissues. Potassium is an intracellular cation mainly located in skeletal muscles. It contributes via the Na/K-ATPase pump, to different enzymatic activities and muscle contraction. As a result its deficit contributes to muscle fatigue.

The alterations in electrolyte concentrations are more frequent and more long-lasting during endurance events than in sprints. They vary with fatigue status (Table 6.5). They can be very high

Table 6.5. Electrolytes concentration in horses with fatigue status (Frape, 2004).

	Chlorine	Sodium	Potassium
Tired	3,060	2,120	780
Fit	1,180	880	270

during prolonged exercise carried out under hot and humid climatic conditions: 4,200 mmol/l of Cl, 1,500 mmol/l of K and 3,500 mmol/l of Na.

A proportion of body calcium and magnesium is in the ionised form. This form is involved in muscle contraction and the neuromuscular conduction of calcium and only a secondary function for magnesium. For this proportion calcium and magnesium are considered as electrolytes. The ionised calcium fraction is located in the plasma in the form of free ions (50-60% of plasma calcium) bound to proteins or included in organic or inorganic acid complexes. This is the free ionised fraction, which has a major physiological function in muscle contraction via the calcium pump (Chapter 1, Figure 1.11). Muscle disorders (cramp, tetany, etc.) appear when plasmatic concentration reaches 1.5 mmol/l. The ionised magnesium fraction is located in the cells (99%). The extracellular flux is influenced during exercise by catecholamine production related to increased energy metabolism. Disorders appear as neuromuscular hyperexcitability and sweating.

The acid-alkaline equilibrium in the intra and extracellular fluids must be maintained to promote performance. This equilibrium, or cation-anion balance, is calculated from the difference between cations and anions that is referred to as DCAB (Dietary Cation Anion Balance) using the standard model established by Rion (2001).

DCAB (m Eq/kg DM ration) = $(Na^+ + K^+ + Ca^{2+} + Mg^{2+}) – (Cl^- + H_2PO_4^- + SO_4^-)$

Na^+: ion sodium — Cl^-: ion chlorine
K^+: ion potassium — $H_2PO_4^-$: ion phosphate
Ca^{2+}: ion calcium S — O_4^-: ion sulphate
Mg^{2+}: ion magnesium

Variations in blood and urine pH are very closely linked to fluctuation of cation-anion balance of the ration (Table 6.6).

Cation-anion balance, predicted from the fixed ions content, ranges within 200-300 m Eq/kg DM in normal horse rations. This type of ration reduces the urinary losses of calcium and phosphorus because it maintains pH close to neutrality. As a result other calcium requirements of the skeleton are covered (Table 6.6).

Table 6.6. Variation of pH of blood and urine with the balance cations-anions of the ration (adapted from Frape, 2004).

Balance	Low	Average	High
mEq/kg DM	22	202	357
pH urine	5.38	7.69	8.34
pH blood	7.37	7.40	7.40

6.2 Nutritional expenditure

6.2.1 Energy expenditure

6.2.1.1 At rest: maintenance

Maintenance corresponds to the energy expenditure of a horse box-stalled without exercise, i.e. at total rest. The expenditure averages 0.0373 UFC/kg $BW^{0.75}$, i.e. 3.9 UFC and 5.1 UFC for horses weighing 500 kg and 700 kg, respectively. This minimum varies with breeds (Table 6.7 and Chapter 1). The maintenance expenditure of horse box-stalled during a period of work is higher due to an increase in general metabolism related to work. This elevation is quite different according to the type of work (Table 6.7).

6.2.1.2 Working

Locomotion increases the horse's expenditure compared to rest, which is primarily a result of skeletal muscle work. Increasing cardiovascular-respiratory systems activity as well as other organs, and the elevation of tonus in other muscles also contribute. The increase of oxygen uptake (about 1 litre for 25 l inspired air) is the best criterion. It has been experimentally measured with horses working on a treadmill, then on a track using more and more sophisticated mobile equipment

Kinetics of expenditure

Before exercise, energy expenditure is anticipated but no increase in oxygen uptake occurs (Figure 6.2). This deficit lasts for only 1 to 2 minutes; it amounts 30 to 128 ml/kg BW of oxygen. This demand is satisfied through anaerobically consuming body reserves (Chapter 1, Figure 1.2). At the end of a period of exercise, energy expenditure remains higher than that observed at complete rest because oxygen uptake decreases slowly (Figure 6.2). This oxygen uptake corresponds to the oxygen debt created during exercise. Oxygen uptake is the best criteria to evaluate energy expenditure. It averages 3 ml/kg BW at rest then increases during exercise with velocity until 550-600 m/min whatever the activity (race, sport or drafting) (Figure 6.5). Oxygen uptake can be predicted with the model designed by Hornicke *et al.* (1983); using experimental data obtained by the same group of Meixner *et al.* (1981) in horses ridden on a track.

O_2 uptake (l/min) = 3.78 + 0.097 velocity (m/min).

Table 6.7. Elevation of maintenance expenditure in horse box-stalled during working period (%).[1]

Breeds	Draft	Riding	Racing
At rest	0	5	10
Working period	+5 to +10	+10 to +25	+30 to +40

[1] Evaluation for ponies is displayed in Chapter 8

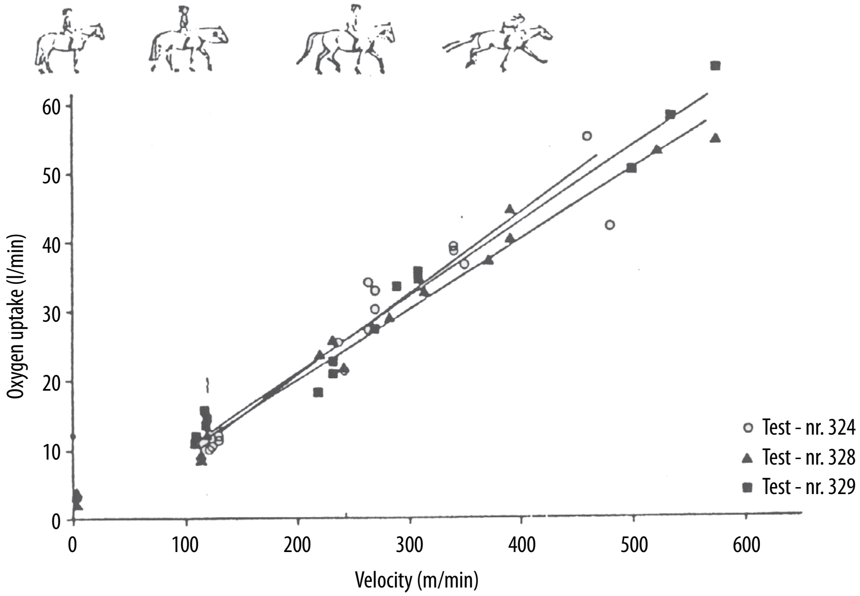

Figure 6.5. Relationship between oxygen uptake (O_2) and velocity (V) during an exercise test (adapted from Meixner *et al.*, 1981).

At the highest velocity that has been studied on a track, 600 to 700 m/min, oxygen uptake is 100 ml/kg BW. In horses exercised on a tread mill at a maximal velocity of 800 m/min, oxygen uptake reaches 125 ml/kg BW. In trained horses maximal oxygen uptake could range from 140 to 185 ml/kg BW. At maximal intensity, the metabolism is predominantly anaerobic. Conversely, during endurance races of at least 100 km, oxygen uptake ranges within 40 to 80 ml/kg BW and metabolism is aerobic.

It should be stressed that oxygen uptake is independent of velocity when it is expressed in respect of distance only: 0.21 ml/kg BW/m at rest; 0.19 at a trot or gallop (oxygen debt not included in this last case). In addition, the optimal oxygen uptake ranges from 0.12 to 0.20 ml O_2/kg BW/m according to the gait.

Evaluation and variation of energy expenditure

Energy expenditure has been calculated during exercise using oxygen uptake multiplied by the thermal equivalent (kcal/O_2) corresponding to a respiratory quotient (R.Q.) determined at each measurement. The energy expenditure rises exponentially with the velocity because the efficiency rate of energy decreases (Figure 6.6).

In respect to energy expenditure at rest, which is 11.5 kcal/min, the energy expenditure of locomotion of the horse is multiplied by 4; 10 to 15; 20 to 40; and about 60 times at walk, trot, gallop and maximum speed respectively. The bases for calculation of energy requirements of sport, leisure and race horses are mentioned in the Table 6.8.

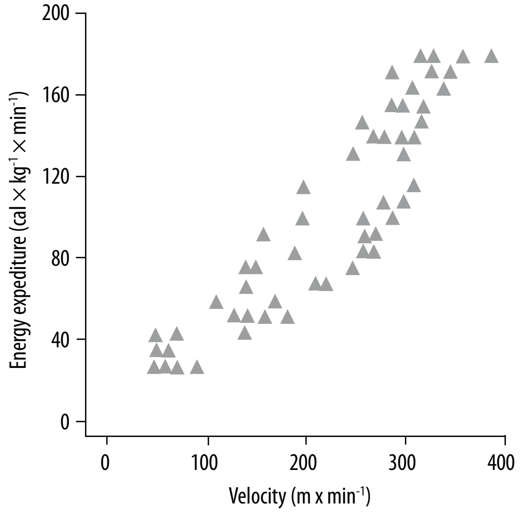

Figure 6.6. Relationship between energy expenditure (E) and velocity (V) in sport horse (adapted from Pagan and Hintz, 1986a,b).

Table 6.8. Variation of energy expenditure with velocity; bases designed by INRA to establish energy requirement in sport and leisure horse at work[1] and the Thoroughbred racehorse (Vermorel *et al.*, 1984).

Situation	Velocity (m/min)	Energy expenditure	
		(kcal/min)	Multiples of maintenance
Waiting	0	11.5	1.1
Standing up with the rider	0	12	1.2
Walk	110	50	2.5
Light trot	200	110	10.0
Normal trot	300	160	15.0
Fast trot[2]	500	350	35.0
Normal gallop[2]	350	210	20.0
Fast gallop ('Canter')	500	330	29.0
Very fast gallop ('Bout')[3]	800	493	45.0
Maximal velocity[3]		(600)	(55.0)

[1] Energy expenditures were calculated from oxygen uptake (and oxygen debt) measured by Meixner *et al.* (1981) in horses averaging 560 kg BW loaded with 100 kg (rider + tack + apparatus), but in the case of the horse at walk we used data of Brody and Kibler, 1943; Hoffmann *et al.*, 1967; Nadal'Jack, 1961; Vogelsang *et al.*, 1981; Zuntz and Hagemann, 1898.

[2] Calculated value from maximal oxygen uptake in horses estimated by the authors and oxygen debt.

[3] Racehorse.

The energy expenditure of a horse rises proportionally with bodyweight of either the horse alone or horse + tack + rider because oxygen uptake is a steady 53 and 55 ml/kg/min in both situations. Energy expenditure changes with the duration of work, whatever the gait. For example, the increase ranges from 18 to 36% (7%/h) for 12 to 24 km distances carried out respectively at 80-100 m/min walk. But this effect is influenced by the intensity of work and the onset of fatigue.

Energy expenditure rises quickly with the increase in slope. Oxygen uptake increase ranges from 30 to 50% at a trot (240 m/min) and 50 to 220% at a gallop (580 m/min) when the slope elevates by 5 to 10%. Similarly energy expenditure is 15 times greater when a horse jumps a 1 m obstacle (7 kcal/kg BW/m).

The cost of pulling must be added to maintenance expenditure. Work is described as force (kg) × distance (m), and is expressed in kilogram-metre (kgm). Energy expenditure varies with the efficiency rate of energy for drafting. This was especially well illustrated with draft horses. The pulling force necessary and the work carried out decreases with velocity. Work of 75 kgm/s achieved by a 500 kg BW horse corresponds to draft strength of 68.2 kg carried out at 1.1 m/s or 4 km/h. This is the definition of horsepower. This energy expenditure is 8 times higher than at rest. It rises linearly with the power and duration of work (Figure 6.7A). This relationship was demonstrated in stages using a trotter working on a treadmill and subjected to increasing draft loads (Figure 6.7B).

Limitation: efficiency rate of energy for work

The efficiency rate of energy for work is one of the main limiting factors. The rate is considered as the ratio between the work that is carried out and the corresponding energy expenditure both expressed in calories. The work is the external work that is expressed in kgm multiplied by the thermal equivalent (1 kgm = 2.35 calories). The energy expenditure is the amount of oxygen measured during the exercise (including the debt), multiplied by thermal equivalent: 4.75 to 5.05 kcal of oxygen at the relevant respiratory quotient (R.Q.) determined at the corresponding intensity. The fundamental studies were carried out in drafting horse that furthers to good understanding.

Utilisation of energy for work can be characterized by the net or absolute efficiency rate. The net efficiency rate is the ratio between the work carried out and the energy used for locomotion: locomotion + pulling effort, e.g. the difference between total energy expenditure during work and energy expenditure at rest:

$$\text{Net efficiency rate} = \frac{\text{Work carried out (kcal)}}{\text{Total energy expenditure work (kcal)} - \text{Energy expenditure rest (kcal)}}$$

The absolute rate is the ratio between work carried out and energy expended only to pull the load, e.g. the difference between total energy expenditure during work (kcal) and energy expended during locomotion without the load (kcal):

$$\text{Absolute efficiency rate} = \frac{\text{Work carried out (kcal)}}{\text{Total energy expenditure work (kcal)} - \text{Energy expenditure locomotion without load (kcal)}}$$

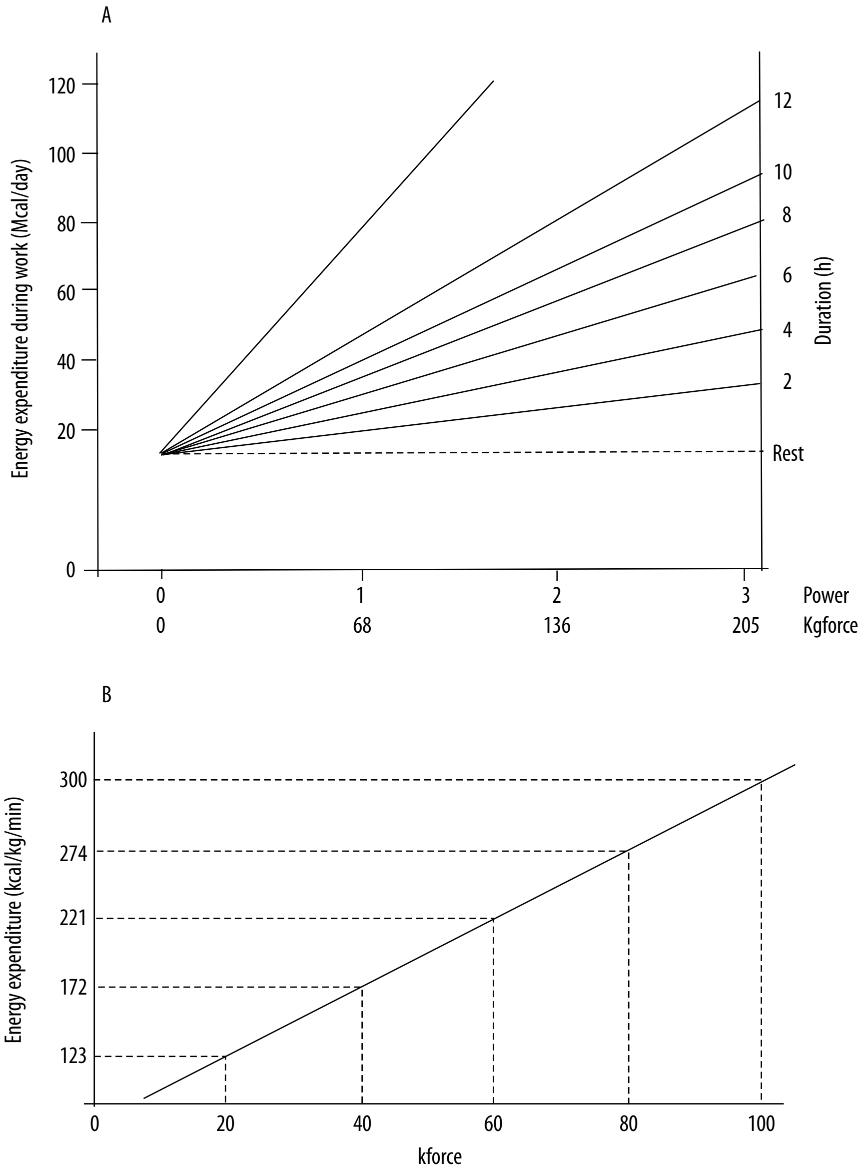

Figure 6.7. Variation of energy expenditure during pulling with the power and the duration. (A) In draft horse (adapted from Brody, 1945). (B) In trotter (adapted from Gottlieb-Vedi *et al.*, 1991).

The net efficiency rate used for locomotion and pulling a load increases with the velocity but plateaus at 28% (Figure 6.8), whereas the absolute efficiency rate used only for pulling the load decreases from 45 to 30% (Figure 6.8). The explanation is simple: as velocity increases, anaerobic metabolism increasingly predominates and ATP production decreases (2 ATP/mole of glucose instead of 38 ATP via aerobic pathway). The efficiency of energy for muscle contraction decreases from 55 to 17%. The

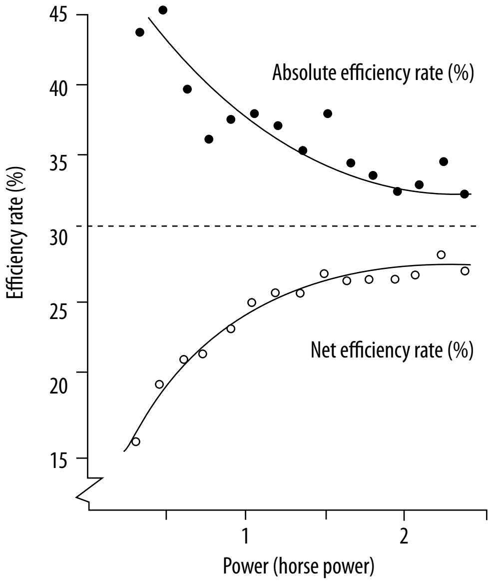

Figure 6.8. Variation of net or absolute efficiency rates of energy for work with the power (adapted from Brody, 1945).

available energy is also used for other purposes: respiration, blood flow, increase in tonus of skeletal muscles other than those directly involved in the exercise. Indeed, only 35% of energy expenditure over maintenance is available for external work (locomotion with or without pulling). The remaining energy is lost as heat (Chapter 1, Figure 1.11).

As a result, the gross efficiency rate which is the ratio between work carried out and total energy expenditure rises exponentially to 18 to 23% with the power dependent on velocity (Figure 6.9).

$$\text{Gross efficiency rate} = \frac{\text{Work carried out (kcal)}}{\text{Total energy expenditure during work (kcal)}}$$

To sum up, the increase in velocity during exercise in horses results in an increase of oxygen uptake and an even more rapid increase in energy expenditure because anaerobic metabolism substitutes increasingly for aerobic metabolism from 300 to 500 m/min according to gait, i.e. VO_{2max} 50 to 60%. The energy efficiency rate decreases despite glycogen being the predominant energy source; lactate production rises exponentially and fatigue takes place.

The proportion of energy provided by aerobic and anaerobic metabolism changes according to the type of exercise and activity (Figure 6.10). 80 to 95% of energy is supplied by aerobic pathways in most activities. As a result the effect of the anaerobic pathway in evaluating energy expenditure is rather limited, except for quarter horse races and very short sprint racing.

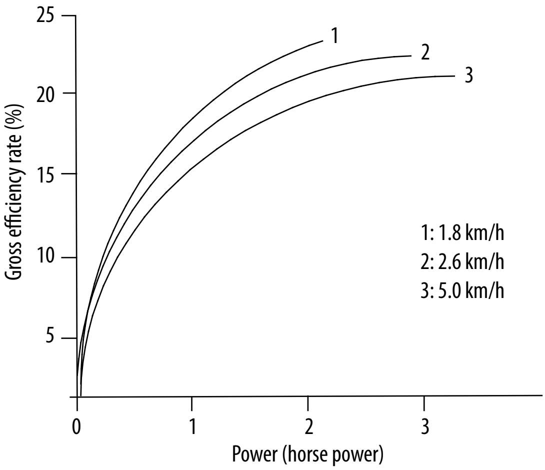

Figure 6.9. Variation of gross efficiency rate of energy for work with the power and the velocity (adapted from Brody, 1945).

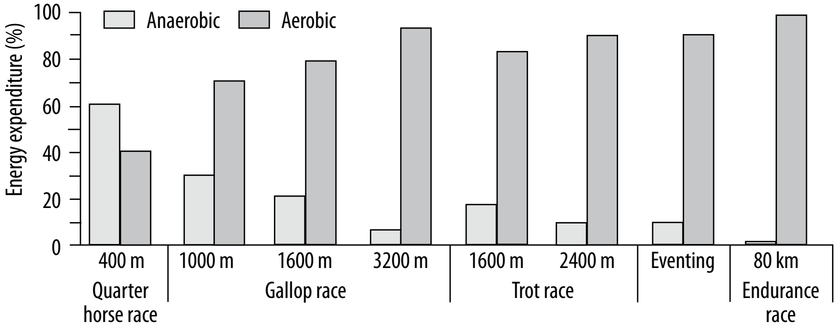

Figure 6.10. Proportion of energy supplied by aerobic and anaerobic metabolism during different activities (adapted from Eaton, 1994).

Energy expenditure after exercise: debt

Following the end of exercise, instantaneous energy expenditure continues to be high over a limited time (2-3 to 20-30 min) according to the intensity and duration of exercise. Oxygen uptake can account for 3 to 5 times the oxygen uptake at the anaerobic threshold (50% VO_{2max}). Lactate concentrations in muscles or in plasma and oxygen uptake are not related during the recovery period. Oxygen debt has been included in the INRA calculation of energy expenditure with respect to velocity (Table 6.8).

Evaluation of exercise intensity

Evaluation of the intensity of exercise is a key issue. Several approaches have been proposed. In the late 19th and early 20th centuries, intensity of pulling was evaluated in Europe using the amount of work done and expressed in kilogrameters (Grandeau in France and Kellner in Germany). The principles were experimentally established in draft horses harnessed to a dynamometric sled. Feed intakes were also measured at different intensities. This approach was validated in the field using thousands of horses of the 'Compagnie des omnibus' in Paris during a number of years (Grandeau and Leclerc; Muntz and Girard). From these studies energy allowances were proposed for different intensities of work. The scientific bases of this approach was developed in the thirties by Brody in USA using both oxygen consumption and the work of harnessed horses on a treadmill. In the late forties recommended allowances were established for draft horses carrying out agricultural work of different intensities. These allowances were characterised by the type of work and corresponding amount of feed intake, measured over many years in Northern Europe (Axelsson; Jespersen ...). Recommended allowances for work of different intensities were proposed in various countries (see review of Olsson and Ruudvere, 1955).

In the eighties NRC proposed to evaluate work intensity and the corresponding energy requirement by arbitrarily assigning an increasing proportion of extra energy above maintenance: 20-50 and 100% (NRC, 1989) then 20, 40, 60 and 90% (NRC, 2007) to the terms light to very heavy work.

In the eighties and early nineties energy expenditure during exercise was evaluated using the relationship between oxygen consumption and velocity (Eaton, 1994; Gottlieb-Vedi *et al.,* 1991; Hornicke *et al.,* 1983; Meixner *et al.*, 1981; Pagan and Hintz, 1986b). From the mid-nineties and into the present century, intensities were evaluated using a relationship between heart rate and oxygen consumption. Several models have been proposed to determine energy expenditure at different velocities during the aerobic phase (Eaton, 1994, Eaton *et al.*, 1995a,b; Coenen, 2008). Using both velocity and heart rate measurements during exercise a more comprehensive estimate of work intensity is proposed. To date, the contribution of the anaerobic phase is in progress. However, heart rate is not a good indicator before and after exercise or at a rest break owing to the unsteady physiological status of the horse and surroundings. In addition, this interesting approach needs to be validated by feeding trials.

Commencing in the early eighties (INRA, 1984, 1990) and up to the present (INRA, 2012) INRA has proposed a very practical approach. It combines the characterisation of one hour standardised work carried out in the field using a variety of situations, an evaluation of the corresponding energy expenditure from oxygen consumption using the most appropriate model for the type of activity and the validation of the estimated intensities with appropriate feeding trials. This should be considered the reference method (Section 6.2.2).

6.2.2 Energy requirements: evaluation

6.2.2.1 Sport – leisure

Energy expenditures for work that are added to the maintenance expenditure of a horse at rest, to evaluate total daily energy expenditure are a result of 4 components:

1. The duration of work, the only one which is easy to measure: it is more or less standardised in riding schools and training centres.
2. The intensity of work: the energy expenditure of one hour of exercise is highly variable (compared to that of the yield of one kilo of milk or even one kilo of daily gain).
3. The side effects of work: expenditure linked to the recovery period after exercise until rest, (oxygen debt, etc.), but also the anticipation of expenditure (stress) before working, for example when a horse is saddled.
4. A general elevation of metabolism, which is likely, during a period of intensive work (training to competition, etc.) and which results in the increase of maintenance expenditure even at rest.

For practical applications, the range of energy costs (UFC) of a standardised hour of work carried out by horses in primary field situations, were evaluated (Figure 6.11). For that purpose two methods were implemented, one is analytical and the other one is global.

Using the analytical method, each hour of work was broken down into different periods corresponding to different types of exercise (walk, trot, jumping, etc.) carried out over various durations, which were measured in field surveys. The duration of each period was multiplied by the energy cost previously established for the specific type of exercise (Table 6.8). Step by step the energy cost of a standardised hour of work was evaluated for different intensities of work carried out in a variety of practical

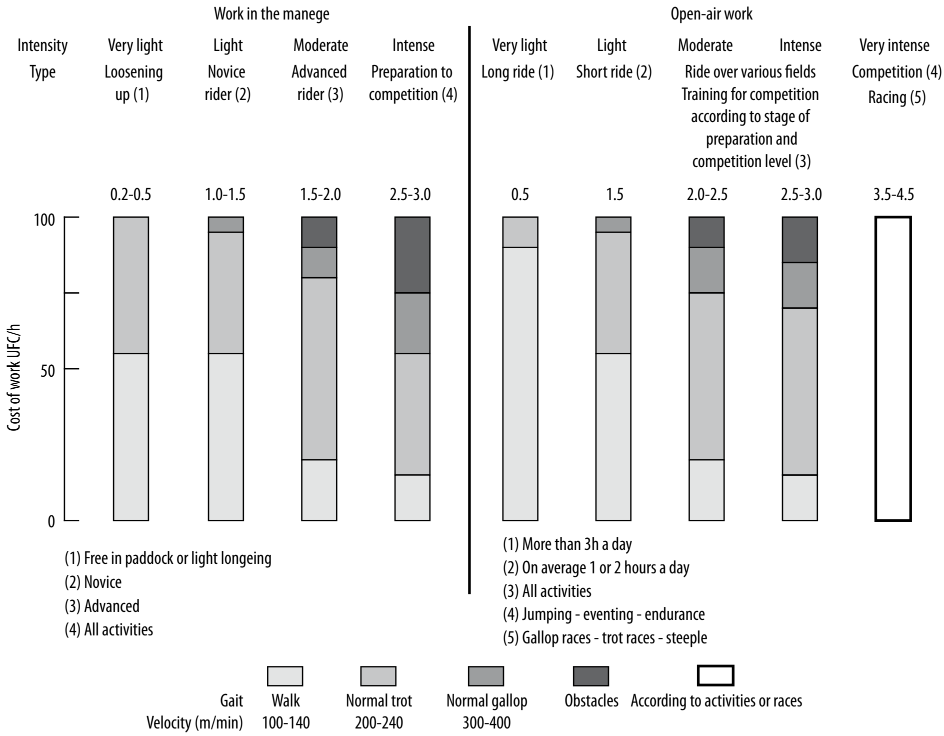

Figure 6.11. Variation of energy cost of one hour of work of sport, leisure and race-horses according to the type and duration of exercise.

situations by adding up the energy cost of each activity (Figure 6.11). The intensity of one hour of work results from the energy cost of the different types of exercise undertaken during this hour. Even if the components (a) and (b) were accurately evaluated, the impact of the other two components (c) and (d) remain either approximate or unknown. The eventual interactions between the different periods, and the efficiency of metabolisable energy for the different activities remain questionable.

It must be noted that in using the global method, the energy intake of adult horses, required to maintain constant bodyweight and body condition score is measured while undergoing different activities (Chapter 1) This method is the most relevant as it is based on practical and physiological aspects. It takes into account all four components. However, this method should be implemented in very precise situations, which must be described in detail. Work, feed intake, bodyweight and body condition scores of horses should be measured precisely over time. Such precision is rarely carried out and/or reported in published feeding experiments.

To date the two methods have been used in a step-wise approach to establish the requirements and the recommended allowances for sport and leisure horses in two big professional facilities: the internationally recognised National Riding School in Saumur, France (Ecole Nationale d'Equitation: ENE) and the Center for Animal Science Education in Rambouillet (CEZ). In the first step, using the analytical method, the energy cost of one hour of work was evaluated according to the method previously described for the horses ridden in the two facilities. These hourly costs were increased by 10 to 20% to include the side effects (c) and the general elevation of metabolism (d). Maintenance requirements were also increased according to the effect of breed and activity (Table 6.7). These additional costs are still approximate in the context of present knowledge. Eighty sport horses were involved at ENE and 18 leisure horses at CEZ during 10 and 4 months respectively. At ENE, the horses were weekly ridden two hours a day during five days for training instructors and involved in competition one or two times a month according to the disciplines: show jumping or eventing (national level). At CEZ the horse were weekly involved in the education of late beginners or qualified riders during six days. The horses that were ridden by qualified riders competed in show jumping once a month (regional level). Individual energy requirement of horses (UFC) were evaluated according to their bodyweight and body condition score and the characteristics of the work they performed. In the second step, this preliminary evaluation of requirements performed individually for all horses prior to the two feeding trials were compared to the individual energy intake measured daily (UFC: net energy of feeds was determined by indirect calorimetry) to calculate the individual energy balance for all horses including any variation of body energy reserves (Chapter 1). The energy intake and energy requirements were comparable (for example, Table 6.9).

For practical applications, the range of energy costs of one standardised hour of work in the principal situations encountered for sport and leisure horses as well as total energy requirements are relevant (Figure 6.11). These materials were used to evaluate the requirements and recommended allowances (Table 6.13 to 6.16).

6.2.2.2 Racing

Energy expenditure was estimated in Trotters exercised on a treadmill using the model proposed by Gottlieb-Vedi (1991), that is more specific than that previously used for sport horse.

Table 6.9. Energy balance of horses in a riding school (Martin-Rosset *et al.*, 2008b).

	Group A (horses for beginning riders)	Group B (horses for qualified riders)
Number of horses	8	10
Duration (days)[1]	68	97
Bodyweight (kg)		
Initial	562.8±51.8	562.1±36.4
Final	564.2±54.0	561.5±42.8
Body condition score[2]		
Initial	2.63±0.23	2.95±0.48
Final	2.81±0.25	2.98±0.59
Intake (kg DM/d)[3]		
Wheat straw	7.0±0.36	2.72±0.00
Grassland hay	-	1.10±0.00
Compound feed	7.13±0.37	6.46±0.43
Total/d	14.13±0.73	10.28±0.43
Total/kg BW	2.51	1.83
Work[4]		
Duration (min/d)	120±16	50±0.00
Intensity	moderate	high
Energy balance UFC/d/horse		
Ingested	8.70±0.45	7.39±0.39
Expenditure[5]	9.05±0.63	7.33±0.43
Difference	-0.35±0.35	+0.06±0.28

[1] Horses were adapted during 1.5 month before experimental period.

[2] Méthod INRA/HN/IE, 1997; Martin-Rosset *et al.*, 2008a (Chapter 1, Table 1.4).

[3] DM: dry matter.

[4] Duration of exercise carried out at different gait was measured using a chronometer and the number of jumped obstacles was counted.

[5] See Section 6.2.1.1 and 6.2.1.2.

O_2 uptake (l/min) = 5.85 + 9.84 velocity (m/min)

In a Trotter the expenditures used to evaluate the requirements were calculated for a trained horse 560 kg BW pulling a sulky + driver = 80 kg at various velocities. The oxygen debt linked directly to the exercise was also estimated and then added to the expenditure of the exercise (Table 6.10).

Energy expenditure was estimated in race-horses (Thoroughbred) using the model of Hornicke *et al.* (1983), adding oxygen debt (Table 6.8). The requirements were evaluated from expenditures calculated for a trained horse, 540 kg BW, ridden by a Jockey + Tack = 60 kg. Comparing this evaluation to that measured on the same horse trained on a treadmill according to a similar program, this estimation was slightly higher.

Table 6.10. Variation of energy expenditure with the velocity in the Trotter.

	Velocity (m/min)	Energy expenditure	
		Kcal/min	Multiples of maintenance
Waiting	-	13	1.3
Walk	110	37	3.4
Normal trot	300	135	12.3
Fast trot[1]	500	310	28.2
Very fast trot[1]	700	440	40.0
Maximal trot[1]	850	530	48.1

[1] Oxygen debt included.

6.2.2.3 Pulling

The expense of locomotion is added to that of pulling the load. The pulling work results from the force that is applied (kg) multiplied by the distance (m), and it is expressed in kilogrammeter (kgm). The pulling force is a result of the weight of the vehicle multiplied by the movement coefficient. This coefficient depends on the vehicle characteristics (wheel diameter, friction, etc.) and those of the road. The coefficient range is generally within 1 and 4% referring to data obtained at the end of 19th century by Morin, de Gasparin, Lavalard and Grandeau, reported by Gouin (1932).

The average force applied by a horse during a period of work as velocity rises, declines from 70 kg at a walk to 25 kg at a fast trot (Table 6.11). Similarly, the daily amount of work produced decreases as well. Referring to American and French data obtained in the early 20th century this amount of work reaches a maximum when a horse is pulling a load at a walk (3.3 to 4.0 km/h) with a mean pulling force which ranges between 1/8 to 1/10 of its weight, which corresponds to a horse power (75 kgm/s). A good draft horse, well managed, can work approximately ten hours a day and carries out a work load, which ranges from 2.3 to 2.5×10^6 kgm (Table 6.11). The pulling force can be much higher at a walk, at least 35% of bodyweight, but for shorter periods. It can peak at 80-100% of bodyweight over a few seconds (often without breathing), which is necessary for example to start a very heavy load.

Table 6.11. Variation of work performed by a 500 kg BW draft horse at specific velocities (Gouin, 1932).

Gait	Velocity (km/h)	Force (kg)	Duration (h, min)	Distance (km)	Work (kgm)
At walk (transport)	4.3	70	8.00	34.4	2,439,000
Slow trot (omnibus)	15.0	38	1.45	16.0	608,000
Normal trot (tramway)	18.0	27	1.30	17.0	458,000
Fast trot (coaches)	20.0	26	1.20	16.0	415,000

In reference to resting values, oxygen uptake is 3 to 8 times higher in horses on a daily work schedule of 6 to 10 hours. It peaks at 20 times. Energy expenditure increases dramatically to 100 times when oxygen debt is included.

Energy requirements for work to be added to maintenance can be calculated from measured expenditures and the efficiency coefficient for energy fed to meet the requirements. However, the most reliable method is the global method, i.e. the measurement of energy intake at work required to maintain a constant bodyweight and body condition score during a period of the same duration.

Previous studies and observations are more or less based on this method (see review of Olsson and Ruudvere, 1955). The recommended allowances established at that time related to the amount of work carried out daily and described as light, moderate, heavy and very heavy. Jespersen (1949) proposed the following requirements expressed in Scandinavian FU (Feed Unit: FUsc):

- very light: 0.2;
- light: 0.3;
- moderate: 0.5;
- heavy: 0.7;
- very heavy: 1.0.

Those data are easy to use since the concentrates fed to meet energy requirement for work have UFC values very close to FUsc.

6.2.3 Nitrogen expenditure and requirement

6.2.3.1 At rest: maintenance

The expenditure is fixed at 2.8 g MADC/kg $BW^{0.75}$. It is related to energy expenditure according to a ratio 65-70 g MADC/UFC.

6.2.3.2 Work

Kellner, in 1909, conducted studies in Germany, which established that nitrogen expenditure rises with the intensity of exercise when the daily ration does not satisfy energy expenditure. More recently, it has been shown that protein synthesis in muscles and the digestive wall decreases and catabolism increases during exercise. Some amino acids are used as an energy source by oxidation of the carbon skeleton when exercise is very intense and energy supply limiting. Amino groups are transported to the liver where they are used either for synthesis of non-essential amino acids or excreted as urea. The transportation form is alanine to permit the transamination of amine groups that are bound to pyruvate to be involved in the neoglucogenesis. The plasma concentrations of alanine and uric acid are known to increase during moderate and endurance exercise. Nitrogen catabolism, like energy, continues after the exercise ends. Urea is mainly excreted in sweat since renal excretion does not change during exercise (Chapter 1, Table 1.3) but oxidation of branched amino acids (leucine, isoleucine and valine) to supply energy has not yet been documented in horses as it has in human.

Nitrogen retention increases during training periods. Retention increases faster than nitrogen intake. That is why muscle mass increases in horses during training periods of submaximal exercise.

Sweat nitrogen losses rise whereas urinary nitrogen losses are little changed. During an 80 km endurance race ridden at 18 km/h, nitrogen sweat losses range from 2-3 mg/kg $BW^{0.75}$/h. These losses increase with nitrogen content of the ration. Nitrogen losses have been estimated at 25-37 g during intense exercise.

It is accepted that the amount of nitrogen expenditure rises more slowly than energy expenditure with intensity and duration of exercise. However, it may be higher when body protein is involved to compensate for the shortage of energy allowances or energy body reserves. In normal conditions, those nitrogen expenditures are always covered as soon as feed intake increases to meet energy expenditures owing to the nitrogen content of both forages and cereal grains (or compound feeds) routinely fed to exercising horse. Thus, it is not necessary to increase nitrogen concentration (MADC) of exercising horses with respect to the resting horse. The nitrogen expenditure is fixed at 65-70 g MADC /UFC in adult horses maintained at constant bodyweight.

Training objectives, primarily during the phase prior to competition, are to raise muscle mass (e.g. lean mass) and enzyme and haemoglobin concentrations. In the adult horse in training fed increasing ration quantities with a constant nitrogen/energy ratio, nitrogen retention increases more quickly than the elevation of intake until it plateaus. This could explain muscle growth. The nitrogen expenditure linked to the increase of muscle mass in adult horses will be covered by increased ration intake with a N/E= 65-70 g MADC/additional UFC.

Most of horses enter competition as 2 or 4-years old. Protein synthesis is 2 to 3 times higher in young horses than in adult horses. The amount of synthesised protein changes in parallel with the mount of protein fixed, and thus with daily gain. However, it relies on protein and energy intake owing to their additive effects. In these situations, the N/E ratio of additional allowances should range from 50 to 60 g MADC / additional UFC for 2 and 3-4 year olds respectively (Chapter 5).

These requirements were determined in the same feeding trials carried out by INRA to evaluate energy requirements.

6.2.4 Minerals and electrolytes expenditures and requirements

6.2.4.1 Minerals

The expenditures and requirements were established using feeding trials. Calcium and phosphorus are principal players in maintaining skeletal integrity in exercising horses. **Calcium** is also involved in muscular contraction. Exercise stimulates bone formation and calcium deposition. Thus, there is an added calcium requirement to be covered.

In the adult horse, total requirement (rest + work) depends on the intensity of exercise. Requirement is calculated using the following models:

- Rest: g Ca/d = 0.04 g Ca × BW kg;
- Light intensity: g Ca/d = 0.06 g Ca × BW kg;
- Moderate intensity: g Ca/j = 0.07 g Ca × BW kg;
- High intensity: g Ca/d = 0.08 g Ca × BW kg.

In the young horse the requirement is calculated using the model proposed in Chapter 5:

g Ca/d = (0.072 g Ca × BW kg) + (32.0 g Ca × bodyweight gain kg).

Phosphorus retention is not affected by exercise in adult and young horses. In the adult horse total requirement (rest + work) is calculated using the following models:
- Rest: g P/d = 0.028 g P × BW kg;
- Light intensity: g P/d = 0.038 g P × BW kg;
- Moderate intensity: g P/d = 0.042 g P × BW kg;
- High intensity: g P/d = 0.058 g P × BW kg.

In the young horse the requirement is calculated using the following model:

g P/d = (0.04 g P × BW kg) + (17.8 g P × bodyweight gain kg)

This model corresponds to that designed for growth (Chapter 5). Requirement for work is also met because the additional allowance beyond the calculated requirement does not improve phosphorus retention.

Requirement and retention of **magnesium** are both increased by exercise in adult horse. In adult horse total requirement (rest + work) is calculated using the following models:
- Rest: g Mg/d = 0.015 g Mg × BW kg;
- Light intensity: g Mg/d = 0.019 g Mg × BW kg;
- Moderate intensity: g Mg/d = 0.023 g Mg × BW kg;
- High intensity: g Mg/d = 0.030 g Mg × BW kg.

In the young horse, the requirement corresponding to growth and work is calculated using the model proposed in Chapter 5:

g Mg/d = (0.015g Mg) + (1.25 g Mg × bodyweight gain kg).

6.2.4.2 Electrolytes

Referring to the review of recent studies, bodyweight losses (Δ BW kg) related to sweating during routine exercise would be: 0.3% (light intensity) – 0.5% (moderate intensity), 1.0% (high intensity) and 2.0% (very high intensity). However, bodyweight losses during very high level competitions in endurance or eventing would range from 4 to 8%.

Sodium losses corresponding to urinary and faecal losses are estimated at 0.02 g/kg BW at maintenance. Exercise losses are 2.8 g Na/litre of produced sweat which correspond to 3.1 g Na intake with a sodium digestibility of 90%. Total requirement (rest + work) is calculated using the following models:
- Rest: g Na/d = 0.02 g Na × BW kg;
- Light intensity: g Na/d = (0.02 g Na × BW kg) + [3.1 g Na × (Δ BW kg = 0.003 × BW)];
- Moderate intensity: g Na/d = (0.02 g Na × BW kg) + [3.1 g Na × (Δ BW kg = 0.006 × BW)];
- High intensity: g Na/d = (0.02 g Na × BW kg) + [3.1 g Na × (Δ BW kg = 0.01 × BW)];

- Very high intensity: g Na/d = (0.02 g Na × BW kg) + [3.1 g Na × (Δ BW kg = 0.02 × BW)];
- Competition (national – international): g Na/d = (0.02 g Na × BW kg) + [3.1 g Na × (Δ BW kg = 0.04 to 0. 08 × BW)].

The **chlorine** loss at maintenance amounts to 0.08 g/kg BW including urinary, faecal and cutaneous endogenous losses and those related to perspiration. Losses during exercise are expressed in regard to sweat production: 5.3 g/l of sweat or 5.3 g/kg BW. Digestibility of chlorine is 100%. Total requirements (rest + work) are calculated using the following models:

- Rest: g Cl/d = 0.08 g Cl × BW kg;
- Light intensity: g Cl/d = (0.08 g Cl × BW kg) + [5.3 g Cl × (Δ BW kg = 0.003 × BW)];
- Moderate intensity: g Cl/d = (0.08 g Cl × BW kg) + [5.3 g Cl × (Δ BW kg = 0.006 × BW)];
- High intensity: g Cl/d = (0.08 g Cl × BW kg) + [5.3 g Cl × (Δ BW kg = 0.01 × BW)];
- Very high intensity: g Cl/d = (0.08 g Cl × BW kg) + [5.3 g Cl × (Δ BW kg = 0.02× BW)];
- Competition (national – international): g Cl/d = (0.08 g Cl × BW kg) + [5.3 g Cl × (Δ BW kg = 0.04 to 0.008 × BW)].

Meeting the chlorine requirement should consider sodium since these two electrolytes are associated as sodium chloride (NaCl). Plasma chlorine concentration is a good indicator of its status: it ranges between 94-104 mmole/l.

Potassium losses corresponding to urinary and faecal losses are estimated at 0.05 g/kg BW at maintenance. Exercise losses amount to 1.4 g/l of sweat and the requirement is 2.8 g/l as digestibility of potassium is 50%. The total requirement is calculated using the following models:

- Rest: g K/d = 0.05 g K × BW kg;
- Light intensity: g K/d = (0.05 g K × BW kg) + [2.8 g K × (Δ BW kg = 0.003 × BW)];
- Moderate intensity: g K/d = (0.05 g K × BW kg) + [2.8 g K × (Δ BW kg = 0.006 × BW)];
- High intensity: g K/d = (0.05 g K × BW kg) + [2.8 g K × (Δ BW kg = 0.01 × BW)];
- Very high intensity: g K/d = (0.05 g K × BW kg) + [2.8 g K × (Δ BW kg = 0.02 × BW)];
- Competition (national – international): g K/d = (0.05 g K × BW kg) + [2.8 g K × (Δ BW kg = 0.04 to 0.008 × BW)].

Potassium content of feeds range between 1-2% for forages and oil meals, and 0.3-0.4% for cereals grains (Chapter 12). It should be considered when formulating the ration to meet requirements and manage acid-alkaline balance. Potassium plasma concentrations range from 2.4 to 5.6 mEq/l.

6.2.5 Microminerals expenditure and requirements

Microminerals losses are not well known in horse. Hence, the proposed requirements have a margin of safety. Requirements are suggested per kilo of dry matter intake to consider the large variation of micromineral contents of feeds. They are provided in Chapter 2, Table 2.1. The tolerance thresholds to be considered for these elements are listed in Chapter 2, Table 2.12.

6.2.6 Vitamins requirements

Vitamins requirements are not very well known as very few studies have been carried out over the last two decades. Requirements are expressed per kg dry matter intake and are given in Chapter 2,

Table 2.1. They are very close to those published by INRA (Martin-Rosset, 1990). However, Vitamin E requirement have been updated. Requirements of Niacin PP (vitamin B3), panthotenic acid (vitamin B5) and pyridoxin (vitamin B6) as well as biotin and cyacobolamin are no longer listed as no new studies have confirmed the necessity of supplementation. No recommendations for vitamin C are proposed as endogenous synthesis is sufficient.

6.2.7 Water expenditure and requirement

Losses rely on environmental conditions (temperature and humidity) and the duration of an acclimation period, of intensity and duration of exercise, and fitness of the horse. For a horse weighing 500 kg, at rest in the thermal neutral zone, water intake ranges from 5 to 6 l/100 kg BW or 3.0 to 4.0 l/kg of DM intake depending on the type of diet, i.e. 25 to 30 l/day.

In the exercising horse, water intake estimated from bodyweight loss after exercise (whose major part is fluid losses) increases 2 to 3 times that observed at rest. The total water loss observed following a cross country race has been 20.4 l but it can rise to 28.2 l following a 160 km endurance race, i.e. 4 to 7% of bodyweight before the test. Water is lost via sweating (70 to 92%) and via respiration (18 to 30%). Sweating rises quickly during the first half hour of exercise then plateaus. Total water loss in exercising horse can be 2 to 4 times greater if temperature rises from 20 to 35 °C and humidity increases from 50 to 85%. But sweat losses are reduced in trained and acclimated horses by 70 to 80% compared to non-acclimated horses similarly exercised. The duration of acclimation is 3 weeks.

The predominant factors in the variation of water losses is firstly heat production by the horse related to muscle energy expenditure and secondly to feed intake. The amount of water that is evaporated increases linearly with the quantity of work produced of a similar type. But this loss is higher when the exercise is more intense for the same energy expenditure (e.g. long moderate compared to short intense exercise) as demonstrated in older studies carried out with a horse pulling a load harnessed to dynamometric roundabout.

Water requirements were estimated from studies carried out in the early 20th and 21th centuries in France and in Germany (Chapter 1 and 2) and more recently in Sweden and in Canada (Table 6.12).

6.3 Recommended allowances

6.3.1 Nutrients requirements and recommended allowances for maintenance

The recommended allowances for maintenance (Table 6.13 to 6.19) are averaged values for a horse at rest, box stalled. They take into account the variations mentioned previously (see sections on energy and nitrogen expenditure). However, the horse is still exercised lightly during the resting periods (relaxing in a paddock, lungeing, or short hacking, etc.) to preserve conditioning due to training. In addition, it is established that the maintenance requirement of a horse during the training period is 10 to 40% higher than that of a similar horse at total rest (e.g. without any training) depending on the intensity of training and competition. In this regard, the allowances recommended for temporary rest or very light work in Table 6.13 to 6.17 for light breeds and Table 6.18 and 6.19 for heavy breeds take these factors into account. The recommendations are given in sections entitled 'forced rest horse'

Table 6.12. Water requirements estimation (recent data).[1]

	Ambient temperature (°C)	Duration of work	kg DMI[2]/100 kg BW[3]	kg of total water			Diet
				/kg DMI	/100 kg BW	/Day	
Rest	20	-	1.5-1.6	3.0-3.5	5.0-6.0	24-32	Hay
	30	-	1.5-1.6	6.0-6.5	9.0-10.0	45-50	Hay
Work moderate	20	1 h	2.0-2.2	3.7-4.0	8.0-8.5	40-45	Hay + concentrate
	30	1 h	2.0-2.2	7.0-8.0	16.0-17.0	80-85	Hay + concentrate

[1] For other data: see also Chapter 1 and 2.
[2] DMI = dry matter intake.
[3] BW = bodyweight.

or 'restoration of body condition in a horse after losing weight' for horses that are temporarily at rest under these conditions.

6.3.2 Evaluation of work

The use of a horse is certainly defined by the type of activities that are implemented: racing, sports, leisure, pulling. The type of work is defined by the gait (walk, trot and gallop carried out at the velocities that are routinely used for each type of activity (racing, sport, leisure and pulling).

The amount of work is defined by the duration and intensity. It should be evaluated daily then over a week to smooth the variation in feed requirements between days primarily when horses are managed by amateurs. The duration is easy to measure using a chronometer. The evaluation of intensity may be more difficult. In our conditions, intensity is evaluated after breaking down one standard hour of exercise into the proportion of time carried out at the different gaits using established velocities that are routinely recommended and obstacles (number and height) that are jumped or not according the type of activity. The velocities can be checked more or less daily or over longer intervals depending on the type of activity again using a chronometer. For example, velocity is routinely under tight control during daily training for racing and even during racing. It is increasingly under tight control during endurance or eventing training and competition. Checking velocity can be easily implemented using timed intervals in riding school and even by amateurs involved in sport. Different technologies are commercially available that propose to provide such control.

As a result, INRA recommendations are actually based on average intensities that were measured in the field for each specific activity implemented at different intensities. Scales of intensities are defined for racing, sport, leisure and pulling. The proposed recommendations are averages that may be sufficient for routine riding, training, competing and racing. For those who want to individually refine the evaluation of intensity classes a tool, recording the heart rate, could be used, however, the limits of this approach must be kept in mind (Section 6.2.1.2). This technique will only provide the relative intensity of a work bout for an individual horse at a given time, which may be valuable in monitoring the exercise from a physiological standing point of view. Even for this purpose the recorded data should be expressed in percentage of maximal heart rate because oxygen utilisation is more closely related to this reference than to instantaneous heart rate. It is important to be aware that this tool does not provide the true energy cost of one hour of work as the total cost should include the impact of other components of exercise, which are not and/or cannot be considered using this indicator (Section 6.2.2.1).

6.3.3 Requirements and recommended allowances for sport and leisure horses

6.3.3.1 Specificity of work

The type of use corresponds to the activities that are implemented in practice: equitation for riders with different skills defined by standard levels of the National Federation of Equitation (in France; n=7), work in varied outside conditions, jumping obstacles in open-door facilities or in the country, etc. The velocities used for each gait are those which are officially defined by the French Federation of Equitation and which we have measured in the field. The difficulty of obstacles (height mainly) and the number to be jumped are those which are encountered in professional riding schools.

The intensity of work has been defined by INRA per hour of exercise for each type of use, that is, the sum of the duration of exercise sequences carried out at different gaits and corresponding velocities (Figure 6.11). This evaluation is approximate as it varies with age, skill and temperament of horse, skill of rider and environment. But the measurements we have carried out provide range references on the estimation of hours of standardised work and their distribution according to the different activities (schooling, jumping, etc.), which will undergo additional refinement.

Four intensities of work are identified: very light; light; moderate and intense for a horse working either indoors or outdoors Those intensities are different when the horse is working in the arena or open-door facility and in the field (Figure 6.11).

In practice, the amount of work the horse performs should be recorded daily (number of hours at standard intensities: Figure 6.11) and then weekly (number of hours of exercise at different intensities regrouped by level of intensity). At the end of the week the daily energy allowances to be fed to horse throughout the following week is calculated according to a step-wise procedure (Table 6.13). The sum of energy expenditures of each grouped number of hours of work carried out at a defined standard intensity is multiplied by the corresponding recommended energy expenditure (Figure 6.11). Then the total sum of energy expenditures of work carried out during the full week at different intensities is calculated. This sum is divided by 7 days to evaluate the weighted energy expenditure of one hour of work representative of the intensity of work carried out during this week. This energy cost is used to calculate the amount of feed required by horses with respect daily work performed (Table 6.13).

This is an easily implemented, practical approach because in riding school horses are specialised in their activity. Horses are used according to riders' skills. As a result, their work is standardised. Sport horses are also specialised according to their activities (jumping, eventing, endurance, etc.). They carry out standardised work during training and competition periods as well as through the longer part of the year. Such a practical approach is based on surveys that we have carried out between 1980

Table 6.13. Evaluation of average energy allowances for work to be daily fed to recreational horse[1] in riding school: example of calculation in practical condition.

Day of week	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday	Average
								Per day
Duration (hour)	0.5	1.5	4.0	2.0	2.0	4.0	1.0	15 h/7 = 2.2 h/d
Type of utilisation[2]	(1) A	(1) C	(2) B	(1) B	(1) C	(2) B	(1) D	C
(number of hours)			(2) C	(1) C	(1) D	(2) C		
								Per hour
Energy cost of work (UFC Total/day)	0.2	1.9	6.0	4.0	4.5	6.0	3.0	25.6/15 h = 1.7 UFC/h
(Cost/h × Number of hours)								(e.g. C*: type of utilization
	Average energy cost per day = 1.7 UFC/h × 2.2 h/d = 3.8 UFC/day (to be satisfied daily during the whole week)							

[1] Constant bodyweight (500 kg) and body condition score (3.25).

[2] Intensity of work; A = very light to D = intense (Figure 6.11 – work in riding school or open- air).

and 2008 either in riding schools or in the professional facilities of riders competing at national and international levels. This approach eliminates serious difficulties (see for example Table 6.9).

6.3.3.2 Recommended allowances

The daily requirements for work are added to the requirements of horse at rest (Table 6.14 to 6.17). The energy cost of one hour of standardised work in principal horse facilities, namely in riding schools and sport activities, has been evaluated from energy expenditure of horses measured according to the intensity and duration of each exercise (Figure 6.11). This evaluation includes the costs of anticipation and recovery.

The evaluation of the requirements was validated in the field using recreational and sport horses by measuring the amount of energy intake and work required to maintain constant bodyweight and body condition using horses engaged in the above mentioned activities. As a result the influence of age, temperament and training level of the horse, skill of rider and the surroundings (horse alone or in a group, transportation and climate, etc.) are accounted for in this validation, which provides the recommended energy allowances for each work intensity and type of horse use.

It is recognised that protein requirements of horses are satisfied when the quantities of feeds offered are increased to meet energy requirements. As a result, the protein concentration of the ration for work is close to that of maintenance (65-70 g MADC/UFC). Protein allowances can be increased in young horses to meet the requirements of late growth and muscle development linked to training (Chapter 5, Table 5.11 to 5.14). Minerals and vitamins allowances are also displayed for adult horses (Table 6.14 to 6.17) and for young horses (Chapter 5, Table 5.11 to 5.14).

Table 6.14. Recommended daily nutrient allowances and intake for riding breed adult horse[1] with live weight of **450 kg**.

Utilisation	Daily nutrients allowances																		Dry matter intake[7] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Maintenance																				
At rest[2]	3.8	247	23	18	13	7	9	36	23	78	388	1.6	1.6	310	388	1.6	25,200	3,100	390	7.0-8.5
Work																				
Temporarily rest[3]	4.4	315	29	19	14	7	10	38	24	85	425	1.7	1.7	340	425	1.7	27,600	3,400	425	7.5-9.0
Very light[4,5]	5.0	360	33	27	17	9	13	43	27	90	450	1.8	1.8	360	720	1.8	29,300	3,600	450	8.5-9.5
Light[4,5]	6.6	475	43	27	17	9	13	43	27	105	525	2.1	2.1	420	840	2.1	34,100	4,200	525	9.5-11.5
Moderate[4,5]	7.2	518	47	32	19	10	17	50	31	115	575	2.3	2.3	460	920	2.3	43,100	6,900	920	10.5-12.5
Intense[6]	6.8	492	45	36	26	14	23	60	36	108	538	2.2	2.2	430	860	2.2	40,300	6,450	860	10.0-11.5
Very intense[6]	7.6	547	50	41	28	17	37	84	48	108	538	2.2	2.2	430	860	2.2	40,300	6,450	860	10.0-11.0

[1] See Chapter 5 for young horse in training.

[2] Without any specific work, gelding and mare are concerned by these allowances. For stallion, add 0.4 UFC and 25 g MADC.

[3] Day of weekly rest:

- for horses in riding schools, use the line temporarily rest (4.4 UFC) and increase the proportion of forages in the ration;

- for sports horses, use the line very light work (5.0 UFC) and increase the proportion of forages in the ration.

[4] For a riding school the horse is considered to work 2 hours a day (average observed in the field).

[5] Hacking horse:

in the case of short hacking, very light work for 1 h ride, and light work for 2 h ride;

in the case of long hacking, light work for a ride between 2 to 4 h, and moderate work for a ride longer than 4 h.

[6] Sport horses are considered to work 1 h daily (average observed in the field).

[7] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 6.15. Recommended daily nutrient allowances and intake for riding breed adult horse[1] with live weight of **500 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake[7] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Maintenance																				
At rest[2]	4.1	267	24	20	14	8	10	40	25	85	425	1.7	1.7	340	425	1.7	27,600	3,400	425	7.5-9.5
Work																				
Temporarily rest[3]	4.7	340	31	21	15	8	11	42	26	93	465	1.9	1.9	372	465	1.9	30,200	3,700	465	8.0-10.0
Very light[4,5]	5.3	382	35	30	19	10	15	48	29	98	488	1.9	1.9	390	780	1.9	31,700	3,900	490	9.0-10.5
Light[4,5]	7.1	511	47	30	19	10	15	48	29	113	490	2.3	2.3	450	900	2.3	36,600	4,500	560	10.0-12.5
Moderate[4,5]	7.8	562	51	35	21	12	18	56	33	123	510	2.6	2.6	510	1,020	2.6	47,800	7,700	1,020	11.0-13.5
Intense[6]	7.3	526	48	40	29	15	26	67	39	113	470	2.3	2.3	450	900	2.3	44,100	6,800	900	10.0-12.5
Very intense[6]	8.3	594	54	45	31	19	41	93	53	113	470	2.3	2.3	450	900	2.3	44,100	6,800	900	10.0-12.5

[1] See Chapter 5 for young horse in training.

[2] Without any specific work, Gelding and mare are concerned by these allowances. For stallion, add 0.4 UFC and 25 g MADC.

[3] Day of weekly rest:

- for horses in riding schools, use the line temporarily rest (4.7 UFC) and increase the proportion of forages in the ration;

- for sports horses, use the line very light work (5.3 UFC) and increase the proportion of forages in the ration.

[4] For a riding school the horse is considered to work 2 hours a day (average observed in the field).

[5] Hacking horse:

in the case of short hacking, very light work for 1 h ride, and light work for 2 h ride;

in the case of long hacking, light work for a ride between 2 to 4 h, and moderate work for a ride longer than 4 h.

[6] Sport horses are considered to work 1 h daily (average observed in the field).

[7] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 6.16. Recommended daily nutrient allowances and intake for riding breed adult horse[1] with live weight of **550 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake[7] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Maintenance																				
At rest[2]	4.5	293	27	22	16	8	11	44	28	95	475	1.9	1.9	380	475	1.9	30,900	3,800	475	8.5-10.5
Work																				
Temporarily rest[3]	5.2	373	34	23	17	9	12	46	29	100	500	2.0	2.0	400	500	2.0	32,300	4,000	500	9.0-11.0
Very light[4,5]	5.9	424	39	33	21	11	16	53	33	105	525	2.1	2.1	420	840	2.1	34,100	4,200	525	9.5-11.5
Light[4,5]	7.8	565	51	33	21	11	16	53	33	120	600	2.4	2.4	480	960	2.4	39,000	4,800	600	10.5-13.5
Moderate[4,5]	8.6	620	56	39	23	13	21	62	37	135	675	2.7	2.7	540	1,080	2.7	50,100	8,100	1,080	11.5-15.5
Intense[6]	8.1	580	53	44	32	17	28	73	43	123	613	2.5	2.5	490	980	2.5	45,900	7,500	980	11.0-135
Very intense[6]	9.1	656	60	50	34	20	46	102	59	123	613	2.5	2.5	490	980	2.5	45,900	7,500	980	11.0-13.5

[1] See Chapter 5 for young horse in training.

[2] Without any specific work, Gelding and mare are concerned by these allowances. For stallion, add 0.5 UFC and 30 g MADC.

[3] Day of weekly rest:

- for horses in riding schools, use the line temporarily rest (5.2 UFC) and increase the proportion of forages in the ration;

- for sports horses, use the line very light work (5.9 UFC) and increase the proportion of forages in the ration.

[4] For a riding school the horse is considered to work 2 hours a day (average observed in the field).

[5] Hacking horse:

in the case of short hacking, very light work for 1 h ride, and light work for 2 h ride;

in the case of long hacking, light work for a ride between 2 to 4 h, and moderate work for a ride longer than 4 h.

[6] Sport horses are considered to work 1 h daily (average observed in the field).

[7] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 6.17. Recommended daily nutrient allowances and intake for riding breed adult horse[1] with live weight of **600 kg**.

Utilisation	Daily nutrients allowances																			Dry matter
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[7] (kg)
Maintenance																				
At rest[2]	4.8	312	38	24	17	9	12	48	30	103	513	2.1	2.1	410	513	2.1	33,300	4,100	510	9.0-11.5
Work																				
Temporarily rest[3]	5.5	397	36	25	19	10	13	50	31	110	550	2.2	2.2	440	550	2.2	35,800	4,400	550	9.5-12.0
Very light[4,5]	6.3	450	41	36	23	11	18	58	35	115	575	2.3	2.3	460	920	2.3	37,400	4,600	580	10.5-12.5
Light[4,5]	8.4	603	55	36	23	11	18	58	35	130	650	2.7	2.7	530	1,060	2.7	42,300	5,200	650	11.5-14.5
Moderate[4,5]	9.2	664	60	42	25	14	23	67	40	145	725	2.9	2.9	580	1,160	2.9	54,400	8,700	1,160	13.0-16.0
Intense[6]	8.6.	621	57	48	35	18	31	80	47	130	650	2.7	2.7	530	1,040	2.7.	48,700	7,800	1,040	11.5-14.5
Very intense[6]	9.8	703	64	54	37	22	49	112	64	130	650	2.7	2.7	530	1,040	2.7	48,700	7,800	1,040	11.5-14.5

[1] See Chapter 5 for young horse in training.

[2] Without any specific work, Gelding and mare are concerned by these allowances. For stallion, add 0.5 UFC and 30 g MADC.

[3] Day of weekly rest:

- for horses in riding schools, use the line temporarily rest (5.5 UFC) and increase the proportion of forages in the ration;

- for sports horses, use the line very light work (6.3 UFC) and increase the proportion of forages in the ration.

[4] For a riding school the horse is considered to work 2 hours a day (average observed in the field).

[5] Hacking horse:

in the case of short hacking, very light work for 1 h ride, and light work for 2 h ride;

in the case of long hacking, light work for a ride between 2 to 4 h, and moderate work for a ride longer than 4 h.

[6] Sport horses are considered to work 1 h daily (average observed in the field).

[7] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Recreational and leisure horses

For routine situations (hacking, recreation and sport of low or average levels), the total recommended allowances (maintenance + work) are displayed in the Table 6.14 to 6.17. For long distance hacking, horses may work more than two hours at moderate to intense levels continuously during several days. The horse should be fed quantities corresponding to moderate intensity during several days before and after the hacking to correctly manage body reserves and feed transition. This is the most practical and safe way.

The experienced end-user can always add hourly energy allowances for work (Figure 6.11) to rest requirements of horse keeping in mind previous experience. For example daily allowances over 10 UFC should definitely be treated with caution. Therefore, rations should be formulated on weekly basis to limit any severe and harmful variation. If horses are in good condition body reserves will smooth the variation of daily expenditures.

The overall aim for this category of horses is to maintain body condition score within 3.0 to 3.5.

Sport horses for competition

Feed allowances should also be planned with regard to a work schedule that is fixed in respect to competition goals by using two simple technical reference points, bodyweight and body condition score (Chapter 2). In contrast to recreational horses in riding schools, bodyweight and body condition score may vary within limits because instantaneous requirements are very high and they rise temporally above the physiological and metabolic capacities of the horse to ingest, digest and metabolise a heavy daily ration. Therefore, feeding allowances should definitely be evaluated and implemented on a weekly scale or even over several weeks to carefully manage bodyweight and body condition of the horse. One should keep in mind that, as for fitness, the aim is for bodyweight and body condition score to increasingly be optimal at the right time. Variation of bodyweight and body condition score should not exceed 5% and 0.5 point respectively during the competition period and the minimum body condition score should always be 3, 0 (Chapter 2). Body condition scores over than 3.5 are detrimental.

Endurance

The minimum (and likely optimum) body condition score of endurance horses has been established as 3.0 in order to complete a race and have a chance to win especially for long races (80 to 160 km). If the body condition score is lower than 3.0, for example 2.5, i.e. 25 kg bodyweight loss corresponding to -0.5 body condition score, a body condition score of 3.0 will be restored in about one month if the horse is fed daily 2.1 additional UFC (and 65-70 g MADC/UFC) and work load is kept constant. (The energy supplementation comes from the following calculation: 25 kg bodyweight loss ×2.5 UFC kg BW = 62.5 UFC/30 days = 2.1 UFC/day; Chapter 1 and 2). The daily supplementation should be increased if the time is short. During the last month of training, the event and the following period of recovery the horse should be fed daily 3.0 to 4.0 UFC (and 65-70 g MADC / additional UFC). Allowances of minerals and vitamins are those given in the Table 6.14 to 6.17. There is no need to increase daily electrolytes allowances, except on the day of intense work and only after the work (during race and training) because there is no capacity to store electrolytes as there is with energy prior work competition.

During a long training period, allowances for work increase progressively from 1.0 UFC to 3.0 UFC/hour of exercise until the race because the intensity of exercise rises from light to very intense up to race day (Figure 6.11). General training patterns can be summarised according to Ridgway (1994). Three to five days a week the horse is exercised at a trot (10-15 km/h) during sequences that are increasingly longer (8 to 48 km). Fast trot sequences (20 km/h) or even canter are then introduced, and are separated by walk sequences. Intensity of exercise is moderate close to the race event. Feed allowances should permit the body condition score to range from 3.0 to 3.5 on race-day. This condition level should allow the horse to perform and recover quickly provided the score is not much lower than 3, 0 after the race.

The diet composition will normally average 70 and 30% forage and concentrate, respectively, during training and 60 and 40% during the racing period. However, total daily feed allowances should never exceed 9.0 UFC, especially, and 630 g MADC with some tolerance for protein (Chapter 2) in the adult horse in any period.

Three day events

The event horse undergoes three different tests during two or three subsequent days at novice, intermediate and international levels. The first day is devoted to a dressage test that is ridden using the three gaits and the related speeds that are recommended for each gait in official events. The second day consists of a cross country test composed of 22 to 32 fences, 1.00 to 1.20 m in height along 2,500 to 6,840 m to be carried out at 520 to 570 m/min. In the final day, the horse is involved in show jumping where fence heights range 1.15 m to 1.30 m and number of jumps range from 10 to 15. The energy cost may be high or even very high depending on the event level. The approach to the competition is similar to endurance. During the month prior to the event, during the event, and days of recovery feed allowances range between 2.5 to 3.5 UFC /hour of exercise (and 65-70 g MADC/additional UFC). When the body condition score falls under 3.0 it should be restored using the same routine described for endurance (Chapter 1 and 2). Again allowances of minerals and vitamins are those given in Table 6.14 to 6.17. There is no need to increase daily electrolytes allowances, except for days of intense work and only after the work (during eventing and training), because there is no capacity to store electrolytes as there is with energy. The long training period lasting until one month prior to the event has been very well described (Dyson, 1994; Galloux, 1990). The horse is physically subjected alternatively to dressage, musculoskeletal development, improvement of cardio-respiratory system capacities at trot and gallop, and jumping low fences in an open-air facility. The result is to promote physiological and metabolic adaptations. During this very important period the horse is exercised daily about 1.0 hour. Feed allowances should range within 2.0 to 3.0 UFC per hour of exercise (and 65-70 g MADC / additional UFC) in order to progress from moderate to intense exercise (Figure 6.11) and reach optimal bodyweight and a body condition score of 3.0 specific to the horse.

However, total daily feed allowances should never exceed 9.0 UFC and 630 g MADC with some tolerance for protein (Chapter 2) in adult horses in any period.

Show jumping

Today international show jumping consists of 15 fences including combinations. The dimensions of fences range between 1.50 to 1.70 m high. During a round the average speed ranges between 350 and 400 m/min. But the speed may be 400 m/min. during a scurry jumping with time factor. During the warmup the heart rate averages 100 beats/min. The heart rate rises during the course from 90 beats/min. at gate to 200 beats /min. at peak values. There is a good correlation between heart rates and fence height. The intensity of exercise is moderate during the warmup and the round at such speed. In both situations aerobic metabolism is predominant. But overcoming body's inertia during takeoff and landing cost a large amount of energy. Metabolism during jumping phases is anaerobic. Jumping is a strenuous effort because plasma cortisol concentration elevates twice time more than at rest. And fatigue occurs rapidly as far as the heart rate is often in excess of 150-160 beats/min. Energy expenditure would be equivalent to galloping the same distance at 600 m/min. The duration of exercise averages one hour including warmup – course – short term recovery. Feed allowances would range within 2.0-3.0 UFC /h exercise (and 65-70 g MADC/additional UFC) when body condition score is optimal 3.00-3.25. It is detrimental for performance and health (joints) to go beyond this optimum body condition score. We should remind that a variation score of 0.25 corresponds to a variation of 13 kg body weight which in turn corresponds to a variation of 1.0 to 1.4 UFC/kg BW to be corrected (Chapter 2, Table 2.4). It is stressed to implement all the feed allowance recommendations. It is useless to increase electrolytes supplementation before competition because the horse has no capacity to store extra allowances. Hence supplementation should take place after competition.

The show jumping horses are subjected to a long term program all the yearlong including more or less long training depending on the experience of the horses and to a rest period placed mostly in early winter. Horses are trained subsequently on flat, over fences and conditioned prior the competitions (Clayton, 1994). During the flat sequence the show jumpers are schooled to move easily laterally and to adjust their stride length according to the rider's aids. The intensity of exercise is moderate and feed allowances average 2.0 UFC/h work. Then the show jumpers are subjected to training over fences to strengthen the power of the appropriate muscles groups and to improve the technical jumping skills. Gymnastic Jumping at different gaits over rails placed at different distances is carried out to improve the coordination. The intensity of exercise is again moderate and feed allowances average 2.0 UFC/h work. Prior the period of competition, the show jumpers are conditioned to promote aerobic capacity (cardiovascular conditioning or interval-training), to enhance explosive power in the muscles (strength training and anaerobic capacity) and to maximize athletic ability (suppling exercises). The intensity of exercise during this conditioning sequence is high while the horses are cantering and jumping fences. The duration of exercise during this sequence does not exceed one hour including warmup and short term recovery. Feed allowances range within 2.0-2.5 UFC/h work.

The feeding goal to be reached in show jumping horses is to maintain optimal body condition score in a narrow range 3.25-3.50 depending on the age and experience of the horses, competition level, and time intervals between competition and prior the next competition. Hence body condition score and body weight should be monitored biweekly and weekly respectively. It is recommended to smooth the variation of feed allowances and diet composition (forage/concentrate ratio). Feed allowances should be estimated and scheduled at week scale (see example given for recreational horse: Table 6.13). The minerals allowances should be met using appropriate mineral supplements and they should be balanced to prevent or worst to fix bone disorders.

Ration formulation

Energy intake estimated in UFC from data obtained from two surveys carried out in Elite-Show Jumpers (Martin *et al.*, 2008), and very recently in Elite-Eventers (Martin, unpublished data) supports these recommandations. However, MADC intake exceeds 1.4- and 1.6-fold INRA recommendations, as expected for Elite-Eventers and Elite-Show Jumpers, respectively, regarding the chemical composition of the diet (and the related forage/concentrate ratio: 55/45 and 60/40, respectively). Minerals, electrolytes, trace elements and vitamins allowances of diets exceed far most recommendations and they are often unbalanced as ever in such athletes.

Ration formulation should be on an individual horse basis. The aim is to balance nutrient allowances supplied by feeds that have been chosen through feeds evaluation and tables of recommended nutrient allowances (Table 6.14 to 6.17). Techniques to implement the general procedure are provided in Chapter 2 and 13. Sometimes, protein allowances of the calculated ration can be over recommended levels, mainly when hay (or silage) based rations are supplemented with cereals grains or compound feeds because the protein content of supplements is too close to that of high quality hay. In such situations a maximum 50% excess is tolerated by horses without any apparent detrimental effects to health (where there is no potential renal issue) and performance. But it is much better, for economic reasons, to refine the allowances, substituting some straw to the forage in the diet and to select compound feed with a lower protein content: 90 g MADC/kg DM. Indeed, supplementation with minerals, trace elements and vitamins should not exceed the recommendations and they should be well balanced to avoid any bone and muscle disorders.

Again, the ration formulation and feeding should be planned daily but based on a weekly program.

Mode of feeds distribution

On a daily scale, the ration should be fed at regular times. The number of meals is generally three: morning, midday and evening. Using this time table, distribution of forage and concentrate can be allocated in respect of work activity and wellbeing of the horse (behaviour and health: Chapter 15). When a horse is scheduled to work soon after a meal (2 h at a minimum) only concentrate is fed. The concentrate is ingested very quickly (1 kg of oat takes 10-15 min vs 1 kg hay, 40 min) and easily digested (namely within 2 h on average in the small intestine; to date, little insulin limiting impact is expected on energy released during exercise). Therefore, the stomach is not too bulky before exercise. In contrast, there is an advantage to feeding forage when the horse is quiet during a long period (more than 3 h), usually in the evening after work. After forage distribution the horse consumes a long main meal (several hours) and then several small meals at time intervals more or less evenly spaced (Chapter 1). If the horse is managed on straw bedding, feeding behaviour may continue more or less all day and night. This is a recommendation for managing an anxious horse.

On a weekly basis, the daily ration should be as constant as possible, especially for the recreational horse in a riding school or for a hacking horse in an amateur facility. When a horse is working regularly 2 hours a day at moderate intensity, for example, the ration can be evaluated for this 2 hour work interval and maintained constant all the week (except for a resting day). If a horse is working daily 1 to 5 hours at light to moderate intensity a ration evaluated for 3 hours of moderate work can be fed. Rations should be reduced during resting days of course.

This method has the advantage of preventing severe variations of diet composition (forage/concentrate ratio) and amount of concentrates. In general, this method prevents making serious mistakes of ration formulation and evaluation in respect of work. In addition, it promotes better utilisation of the ration and good body condition of the horse.

6.3.4 Requirements and recommended allowances for races-horses

6.3.4.1 Specificity of work

Horses are trained to develop endurance, resistance and ultimately strength and speed to race in top condition. There is a large variety of training programs that are implemented in training centres. This section refers to programs that are published in scientific journals or books to assess requirements and to propose recommended feed allowances. The adult horse is distinguished from a young horse not only in consideration of the requirement of late growth but also working load.

6.3.4.2 Trotter-Standardbred-Pacer

The program published by Lovell (1994), inspired by the American Training Chart (Dancer, 1968), describes the training program very well. The program is divided into three phases: pretraining, foundation training, racing. During the pretraining phase the horse is increasingly subjected to jogging that ranges from 5,000 up to 13,000 m at normal trotting speed. During the foundation phase, the horse alternates during 4 weeks of 10,000 m of jogging at normal trot with jogging at 90% of maximum speed (e.g. maximum heart rate). Ultimately a short phase of racing during 2 weeks when the horse alternates 10,000 m of jogging at normal trot with heats of varying lengths at increasing speeds. Walking intervals are of course included in the different phases of this program.

Requirements were estimated on these bases to get closer to the field conditions. To date INRA has not had the opportunity to carry out experimental feeding trials with this athlete. Some surveys were conducted in open training centers or in private training centers to check the factorial calculations. The recommendations that are displayed in Table 6.18 give an acceptable range.

6.3.4.3 Thoroughbred racehorse

The assessment of requirements was also very pragmatic as in the case of the Trotter. The training program published by Evans (1994) is divided into 3 phases: endurance (4 weeks), combined aerobic/anaerobic, anaerobic (2 weeks), but a pretraining phase (12 up to 20 weeks) should also normally take place. During the pretraining phase, the horse is exercised at a trot or gallop at speeds of 300 to 500 m/min for distances of 3,000 up to 5,000 m. During the endurance phase the horse is exercised over longer distances of 5,000 to 10,000 m at a trot or gallop (canter). The combined aerobic/anaerobic phase horse alternates trotting over 2,000 to 4,000 m distances and galloping at increasing speeds of 500 up to 800 m/min and distance (1,200 up to 3,200 m).In the final phase, the anaerobic capacity is tested to reinforce the speed and acceleration capacity over 600 to 1,200 m distances that are

Table 6.18. Recommended daily nutrient allowances and intake allowances for **race breed** adult horse.

	Daily nutrients allowances																			Dry matter intake[6] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Trotter 560 kg																				
Total rest[1]	4.7	306	28	22	16	8	11	45	28	95	475	1.9	1.9	380	475	1.9	30,900	3,800	475	8.5-10.5
Temporarily rest[2]	6.2	403	37	28	20	11	14	56	35	110	550	2.2	2.2	440	880	2.2	35,800	4,400	550	10.5-11.5
Adaptation[3,5]	8.5	553	50	45	31	17	28	75	44	130	650	2.6	2.6	520	1,040	2.6	48,800	7,800	104	
Foundation training[3]	9.5	618	56	50	34	21	46	104	59	150	750	3.0	3.0	600	1,200	3.0	56,200	9,000	120	12.0-15.0
Speed[3]	8.5	553	50	45	31	17	28	75	44	130	650	3.0	3.0	520	1,040	3.0	48,800	7,800	104	
Thoroughbred 540 kg																				
Total rest[1]	4.6	300	27	22	15	8	11	43	27	95	475	1.9	1.9	380	475	1.9	30,900	3,800	475	8.5-10.5
Temporarily rest[2]	6.1	394	36	27	19	10	14	54	34	110	550	2.2	2.2	440	880	2.2	35,800	4,400	550	10.5-11.5
Phase 1 Adaptation[4,5]	8.5	553	50	43	31	16	28	72	42	130	650	2.6	2.6	520	1,040	2.6	48,800	7,800	104	
Phase 2 Endurance[4]	9.5	618	56	50	34	20	45	100	57	150	750	3.0	3.0	600	1,200	3.0	56,200	9,000	120	12.0-15.0
Phase 3 Aerobic/Anaerobic[4]	9.0	585	53	50	34	20	45	100	57	150	750	3.0	3.0	600	1,200	3.0	56,200	9,000	120	
Phase 4 Anaerobic[4]	9.0	585	53	50	34	20	45	100	57	150	750	3.0	3.0	600	1,200	3.0	56,200	9,000	120	

[1] Maintenance expenditure *sensu stricto* + 10% linked to breed out of training period (break).

[2] Maintenance expenditure *sensu stricto* + 45% linked to breed out of training period (rest day).

[3] Expenditure calculated for Trotter loaded with: sulky + driver = +80 kg.

[4] Expenditure calculated for Thoroughbred loaded with: jockey + hack = + 60kg.

[5] It is possible to increase protein allowances by 20 to 30% during this phase to promote muscular development.

introduced between canter and heats sequences. Walking sequences are of course introduced at timed intervals.

The estimation of total requirements was carried out using this information including walking interval sequences. The factorial calculations were compared with data from surveys. The estimation is consistent with observations in the adult horse but variability of some differences in young horses is larger. The recommended feed allowances are given for adult horses (Table 6.14 to 6.17). For the young horse the recommendations are given in Chapter 5 for growth (Table 5.11 to 5.14), but the cost of work should be added to growth requirements using light to intense levels of work carried out outside (Figure 6.11). Similar recommendations are not yet established for steeple chasers.

6.3.4.4 Ration formulation

The general guidelines of feeding should be applied with some adaptation for race horses owing to feeding behaviour, type of digestion and specificity of nutrient requirements. The balancing of the ration and the type of nutrients should fit the qualitative demand of muscular work that is related to the specific exercise (sprint, middle-distance, long-distance). Genetic type and training method should be considered as well.

Energy sources are of major concern. Glycogen is the main energy source for muscles when sprinting at speeds higher than 500 m/min but this energy reserve is slightly influenced by feeding. Lactic acid is produced by muscles, which can produce muscle acidosis that may result in tying-up. These issues can be prevented if:

- muscle glycogen overloading is prevented using a continuous balance between energy allowances and requirements;
- feeding starch-rich feeds is limited (cereals grains, etc.);
- feeding rapidly absorbed carbohydrates, such as saccharose, prior to races should be eliminated. Indeed, such carbohydrates raise a secondary hypoglycaemia that is detrimental to horse performance.

Energy sources to be fed to race horses are cellulose of forage and storage carbohydrates of cereals grains. Cellulose is digested in the large intestine by the microbial population, which regularly provides volatile fatty acids, a very important source of energy (30 to 60% of the requirements according to forage proportion in the diet: Chapter 1). Cellulose is important too for digestive health (Chapter 2). The small intestine is the principal digestion site for Starch and is absorbed as glucose. In practice the proportion of cereals grains is routinely increased as the amount of work rise. This increase is often too high and too variable. Feeding practice can be improved in different ways.

The amount of grains fed daily should be restricted and the distribution should be divided into at least 3 meals when feeding the athletic horse to prevent digestive and metabolic disorders. For instance, the horses of 'Compagnie des Omnibus' in Paris that were working 8 hours a day in the very early 20th century, were fed 6 meals daily. If the feeding level is high, processing the grains: grinding or rolling, flaking or expansion or extrusion may promote digestion. But this should not lead to increasing the proportion of cereals grains in the diet. Balancing forage to grain ratios will help to prevent muscle metabolism disorders such as exertional rhabdomyolisis, and in young horses the occurrence of osteoarticular disorders. Cereals grains are conventionally fed to horses dedicated to middle or long distance races but they should be reduced for endurance sport horses.

Recent data obtained in Sweden (Swedish University of Agricultural Sciences) with performing Standardbreds show that diets based on high energy forage may be an alternative to the conventional starch-rich diets. No limitation of performance was observed and health was improved (Jansson and Lindberg, 2008). Forages that are fed, should be highly digestible (Chapter 16). Grass forages such timothy and meadow fescue were fed in these studies, eventually supplemented with alfalfa to meet protein requirements (which might be necessary for young horse). The diet was also balanced for minerals and vitamins. The lactate threshold was higher than that found with high concentrate diet. Blood pH was higher than with high concentrate diet which is an advantage to counterbalance the acidosis raised by high intensity exercise. Muscle glycogen content was slightly reduced (-10%). Studies of the effect of such small reductions on performance are still in progress. Maximal voluntary intake ranged between 2.0-2.5 kg DM/100 kg BW. The diet did not become bulky since the digestibility of forage was high and the horses only received 1% of bodyweight. The composition of microbial microflora was more stable with the high forage diet than with a high starch diet.

6.3.4.5 Balancing ration

The diets of athletic horses should be balanced for optimal nutrient concentration and ratios between key nutrients that are specific to type and intensity of exercise and particular diets.

The cellulose content of the diets should average 15% to ensure good digestive system health. Protein requirement will increase slightly with work. Tissue protein will contribute to no more than 4% of energy expenditure when energy intake meets requirements. Protein and energy allowances should be in a fixed ratio of 65-70 g MADC/UFC in adult horses. For young horses in training protein allowances will be increased by 20% (e.g. 78 g MADC/UFC in the total ratio) using good quality protein such as alfalfa meal and soybean meal. The crude protein content of the ration of race horses should average 12-13%. This is also a recommendation for sprinters who are most subjected to stress and the long distance horse whose diet can also be enriched with fat.

Muscular work strongly influences mineral requirements. Recommended calcium and magnesium allowances may be substantially increased in the ration of the athlete. Calcium and magnesium digestibilities are often jeopardised by the usual excess of total phosphorus in conventional diets of race horses. The proportion of cereals grains increases as the work load rises, especially oats, at the expense of forage. Therefore the optimum Ca/P diet ratio of 1.5 is unbalanced by the Ca/P ratio of cereals grains, which is only 0.2-0.3. Supplementation of calcium should be reinforced using a supplement with Ca/P ratio higher than 1.5. Calcium and phosphorus content of the ration should be at a minimum 0.36-0.40% and 0.24-0.30% respectively during intense work periods. Magnesium content is recommended to be at a minimum of 0.15%.

Loss of sodium chloride in sweat is high. It increases with work load, duration, training level and climate conditions. The diet concentration of sodium should be at least 0.30-0.35% (i.e. 3 to 5 g/kg DM). The microminerals allowances are provided on a dry matter intake basis. Intake increases as energy allowances increase (Chapter 2, Table 2.1).

The vitamins allowances (A, D, E) are also based on dry matter intake, which is dictated by energy allowances (Chapter 2, Table 2.1). Vitamin E allowances can be increased if the unsaturated fatty acids content of the ration is high. Huge intakes of vitamins are not effective and may be detrimental, especially for vitamin D. To date there is no good information about the relevance of extra allowances of vitamins B or C in the athletic horse.

6.3.5 Requirements and recommended allowances for draft horses

Recommended allowances were established from feeding trials carried out during the early part of the 20th century and reported by Jespersen (1949) (Table 6.19 and 6.20). Recommended allowances given per hour of work of different intensities is as follows:

- very light: 0.2 UFC;
- light: 0.3 UFC;
- moderate: 0.5 UFC;
- heavy: 0.7 UFC;
- very heavy: 1.0 UFC.

The protein allowances are calculated using the ratio 65-70 g MADC/UFC. These additional allowances are added to maintenance requirements. The allowances should be implemented on a weekly basis to remove daily variation of the ration if the amount of daily work varies.

6.4 Kinetics of allowances for exercise

Feed allowances before, after and during exercise are discussed to stress correct and possibly harmful practices.

6.4.1 Before competition

The last starch-rich meal should be fed no later than 4-5 hours before the event to prevent a series of detrimental physiological and metabolic disorders: elevation of insulin, deep hypoglycaemia and a related definite limitation of available glucose for muscles, a decline in lipolysis with the resulting low availability of long chain fatty acids as an energy source and, finally, depletion of muscle glycogen during exercise ultimately resulting in the occurrence of fatigue. Daily starch allowances are recommended to be no higher than 1.1 g/kg BW, especially when starch has been subjected to an efficient thermal processing, or to restrict to 0.3% BW the amount of cereals grains or starch-rich, processed compound feed during the last meal.

The large intestine is a well-known reservoir of water and electrolytes linked to forage intake. Feeding forages (2 to 3% of BW) up to the final hours prior to an event is recommended for sport horses dedicated to endurance or three day events. The overloading of body heat linked to extra heat produced by the late digestion of forage ingested before the event which would be added to heat production should be a problem. Heat production related to microbial fermentation during the digestion of forage in the large intestine accounts for only 0.5 to 1.0% of total energy intake. The amount of forage consumed during the last period of training before the race or event should not be less than 1.2% BW in race horses and 1.8-2.0% BW in endurance and eventing horses.

Table 6.19. Recommended daily nutrient allowances and intake allowances for draft breed adult horse with live weight of **700 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake[6] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Maintenance																				
At rest[1]	5.1	357	33	28	20	11	14	56	35	100	500	2.0	2.0	400	500	2.0	32,500	4,000	500	9.5-10.5
Work																				
Temporarily rest[2]	5.6	392	36	31	22	12	15	62	39	105	525	2.1	2.1	420	525	2.1	34,100	4,200	525	10.0-11.0
Light[3]	7.7	539	49	42	27	13	25	73	45	128	638	2.6	2.6	510	1,020	2.6	41,400	5,100	638	12.0-13.5
Moderate[4]	8.6	602	55	49	29	16	36	84	51	143	713	2.9	2.9	570	1,140	2.9	53,400	8,600	1,140	13.0-15.5
Intense[5]	10.0	700	64	56	41	21	57	99	59	153	763	3.1	3.1	610	1,220	3.1	57,200	9,200	1,220	14.0-16.5

[1] Without any specific work, gelding and mare are concerned by these allowances. For stallion, add 0.6 UFC and 40 g MADC.

[2] Weekly day of rest:

during period of light work: use the line temporarily rest (5.6 UFC), and increase the proportion of forages in the ration;

during period of moderate or intense work: use the line light work (7.7 UFC) and increase the proportion of forages in the ration.

[3] Light: windrowing.

[4] Moderate: ploughing soft soils, hoeing, harrowing all soils.

[5] Intense: ploughing heavy soils.

[6] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 6.20. Recommended daily nutrient allowances and intake allowances for draft breed adult horse with live weight of **800 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake[6] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Maintenance																				
At rest[1]	5.6	392	36	32	22	12	16	64	40	110	550	2.2	2.2	440	550	2.2	35,800	4,400	550	10.5-11.5
Work																				
Temporarily rest[2]	6.2	434	40	35	24	13	18	70	44	115	575	2.3	2.3	460	575	2.3	37,400	4,600	575	11.0-12.0
Light[3]	7.8	546	50	48	30	15	28	83	51	143	713	2.5	2.5	570	1,140	2.5	46,300	5,700	715	13.0-14.5
Moderate[4]	8.8	616	56	56	34	18	41	96	58	153	763	3.1	3.1	610	1,220	3.1	57,200	9,200	1,220	14.0-16.5
Intense[5]	10.5	735	67	64	46	24	66	118	66	163	813	3.3	3.3	650	1,300	3.3	60,900	9,800	1,300	15.0-17.5

[1] Without any specific work, Gelding and mare are concerned by these allowances. For stallion, add 0.7 UFC and 45 g MADC.

[2] Weekly day of rest:

- during period of light work: use the line temporarily rest (6.2 UFC), and increase the proportion of forages in the ration;

- during period of moderate or intense work: use the line light work (7.8 UFC) and increase the proportion of forages in the ration.

[3] Light: windrowing.

[4] Moderate: ploughing soft soils, hoeing, harrowing all soils.

[5] Intense: ploughing heavy soils.

[6] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Supplementation with water and electrolytes immediately before the event is necessary to promote cardio-respiratory and thermoregulation functions in horses that undergo long distance exercise. Four hours prior to an event, distribution of feed (mixed to improve the palatability) or a paste fed orally and composed of 80 mg Na, 166 mg Cl and 16 mg K, per kg BW will stimulate water consumption and improve the water and electrolyte balance during the event.

6.4.2 During the competition

Compared with the human athlete, there are very few available data for the horse, therefore we should not extrapolate from humans to horses. In endurance horses, during the intermediate rest period, intake of 0.6 kg of concentrate composed of grass meal with the addition of 50% glucose, would increase glycaemia without the depressing effect of insulin and variation of plasma fatty acid concentration. Or 1g of glucose/kg BW would be an option. Fructose should not be offered.

6.4.3 After the competition

Restoration of muscle and hepatic glycogen reserves is a major concern during the recovery period following exercise. Here we can extrapolate from humans to horses. The relevance of starch or a fat meal on muscle glycogen reserves has not yet been demonstrated. It is recommended to offer forage free choice immediately after the competition, then 2-4 hours later 0.3% of BW of a starch-rich meal prepared from cereals grains subjected to thermal processing.

Electrolyte supplementation can be implemented. If water is offered and actually consumed by the horse quantities must be controlled. A paste composed of 76 mg Na, 218 mg Cl and 108 mg K/kg BW may be injected orally, or the electrolytes may be offered mixed with a feeding of grass meal or sugar beet pulp. Water intake should continue to be controlled with a bucket following these distributions until the horse has cooled out.

6.5 Other particular situations

6.5.1 Horse under hot and dry or hot and humid climatic conditions

Horse should maintain a body temperature of 38 °C whatever the environmental conditions. A temperature elevation that averages 2 °C is tolerated by horses. But 2 or 3 weeks of physiological and metabolic adaptation are required for trained horse in hot (>25 °C) and dry or humid (>80% RH) conditions. It is better to have the horse clipped under these conditions. Body temperature results from the balance between heat loss and heat produced by the digestion of feeds, basal metabolism and muscle metabolism related to work (Chapter 1). High temperatures are more difficult for the heavily exercised horse to withstand, especially if the relative humidity (RH) is high and the horse is fed with forage-based or mixed diets without fat (Table 6.21). This is because energy requirements of a horse on these diets is 119-105% more than the reference hay diet supplemented with fat. Therefore, substitution of a proportion of cereals grains by fat (up to 10% of the ration) during an adaptation period of 30 days is recommended. The advantage of this diet is to counterbalance the reduction of appetite that often occurs under hot and humid conditions.

Table 6.21. Determination of the maximum temperature of the environment that is allowed by the thermoregulation attempt during an endurance test of an Olympic level three day-event (Kronfeld, 1996).

Diets composition	Heat production (Mcal/d)	Maximum temperature (°C)
Hay + fat (clipped horse)	21	19
Hay + cereals + fat	21	12
Hay + cereals	22	11
Hay	26	7

Protein allowances should be maintained at a minimum while balancing amino acids (lysine and methionine) because nitrogen concentration of sweat is constant but the ratio protein/urea decreases.

Water requirements can be 200 to 300% higher in hot and humid conditions, because bodyweight loss of the horse can range from 40-50 kg in an endurance race. Sweat production can represent 15% of total body fluids. Hence, it is much better to water a horse with a bucket to control water consumption that may increase by 30%. Electrolyte allowances and supply should be evaluated according to what has already been mentioned (Section 6.4). Horses should be educated to drink slightly salted water during the training period. Horses should be kept quiet to limit water loss linked to acute sweating resulting from stress stimulated by catecholamines production by exercise.

6.5.2 Transport

The effects of transport are limited when the program and transport equipment are well organised. Maintenance energy costs rise by 10 to 50% according to the duration and environmental conditions during travel. Horses should stabilise during the trip even in the standing position as this position is well known to be no more costly than a lying position owing to the locking system of the limbs. Loss of bodyweight ranges within 0.3 to 0.5% per hour of transport. Bodyweight loss relates to the modification of usual feeding regimen, the reduction of the amount of forage distributed and/or ingested by the horse and water intake as a result of variation in digesta content. Bodyweight loss is restored 24 to 72 hours after arrival or possibly later when conditions are hot and humid. Attention should be paid because these variations can result in colics linked to the decline of water content of digesta (colics with stasis) or to microbial fermentation disorders (colics due to abnormal fermentations). Occasionally these disorders may last 2 to 3 weeks. Muscle disorders seem to be limited.

The concentrate fraction (cereals grains or compound feeds) of the diet should be eliminated during transport after it has been increasingly restricted during the three previous days. Hay can be offered (50% of ration) during transport if the hay is not dusty, the transport is short and the van well aired. During transport by aeroplane, hay is more often eliminated owing to air currents due to air-conditioning which may carry dust or microbes through the space. Can wrapped silage be a substitute for hay? It has to be validated. Horse should be watered every 5 hours. Time for recovery should be allocated that is as long as the duration of transport.

6.5.3 Horses at forced rest

A horse may be forced to rest following muscle or tendons disorders, infection, bad body condition (extreme weight loss), culling, etc. Origins of such problems are diverse and it is not planned to discuss all of them.

In most situations, the horse is not at complete rest and maintenance requirements are higher than maintenance *sensu stricto* previously indicated (Chapter 1, Table 1.1). In fact, with the exception of a horse that is totally immobilised by acute disorders, the horse is still lightly exercised (relaxing with lunging exercise, long hacking, etc.) to preserve the benefit of previous training. Feed allowances that may correspond to heavy work should be increasingly reduced (over 3 to 5 days) to meet recommended allowances for temporary rest or light exercise (Table 6.14 to 6.20).

During periods when the horse is at rest or returns to normal work, feeding transition should be implemented over a period of several days to reduce or to increase the allowances and the change in diet composition, especially the amount of concentrates to prevent risks of digestives disorders and overfeeding (colics, laminitis and tying up, etc.).

6.5.4 Restoration of body condition in horse following extreme thinning down

When a horse loses 5 to 10% of bodyweight because of work overload, daily feed intake should be evaluated for maintenance at its normal bodyweight and for body condition restoration. Additional allowances should be calculated because of the change in body condition score (BCS) (Chapter 2, Table 2.4 and 2.5). For example, for a horse weighing 500 kg that has lost 1.0 of BCS (i.e. 55 kg BW), additional daily energy intake should be 2.6 UFC and 80 g MADC / additional UFC for 2 months or 1.7 UFC and 80 g MADC / additional UFC during three months according to the time that is available in the exercising program. In other terms, that means 160 and 140% of normal maintenance requirement respectively (4.1 UFC × 160% = 6.6 UFC of total daily allowances or 4.1 UFC × 140% = 5.7 UFC of total daily allowances, not including the cost of work which needs to be added, keeping in mind that total daily allowances cannot be above 9.0 UFC. Work also requires adjusting to give time for restoration.

6.6 Particular nutritional supplements

Current EU feed legislation does not include a specific definition of 'nutritional supplement'. However, in most EU member states these products are considered as 'complementary feeding stuffs' as they do not cover all daily nutritional requirements of a horse. Nutritional supplements are feed concentrates primarily consisting of carbohydrates, amino acids, highly digestible fibres or fats, electrolytes, trace elements, vitamins, pH regulators, combined in various cocktails. They do not represent a large component of the daily ration and they are fed for short periods. They are expected to improve performances, assuming that the available endogenous amounts are limiting, which has not yet been shown experimentally for most of them.

6.6.1 Nutritional ergogenic aids

The term 'ergogenic' comes from the Greek language 'Ergon' and 'Genic' meaning work and production respectively. In other words, it refers to any agent that would increase work production e.g. amount of work and/or performance (speed, strength, stamina). These agents are classified in five domains of potential influence: physiology – nutrition – mechanics and biomechanics – chemistry and pharmacology and psychology. Only nutritional agents are considered here. Their eventual effects are discussed in relation to energy and nitrogen metabolism.

6.6.1.1 Energy metabolism

L-carnitine

L-carnitine is a co-factor involved in the transport of long-chain fatty acids through the inner mitochondrial membrane where they are oxidised to supply energy to cells. In man, carnitine can be synthesised from lysine and methionine in liver and kidney. However, no performance enhancement with carnitine supplementation has been determined. In the horse, all the trials have shown neither increase in muscle carnitine concentration nor positive modifications of the indicators of exercise (blood concentration of lactic acid, ammonia, and creatine-kinase or aspartate aminotransferase). To date, there is no evidence to support carnitine supplementation in horses. Similarly, inosine has no known benefit yet.

Creatine

Creatine derives from amino acids (methylguanidine-acetic acid). Creatine might be synthesised in the horse, a herbivorous animal, as in vegetarian man, whereas omnivorous man is supplied at least partially from meat. Creatine is usually stored in skeletal muscles in the form of phosphocreatine of which 60% would be phosphorylated (Pcr). Pcr is a source of phosphate for the resynthesis of ATP following short and intense exercise. It might also contribute to buffering ADP accumulation and to improving the low buffering H^+ ions capacity of muscles at normal physiological pH. Unfortunately, neither increase of muscle or plasma concentrations of creatine nor improvement of performance has been observed in horses exercised on a treadmill after supplementation. In humans the effect of supplementation is still controversial and health risks have also been mentioned.

In addition, creatine is an additive that is forbidden by European regulation (EC, 2003; Regulation 1831/2003 Appendix 3 and 4, Annex list of additives, Revision 27).

Ubiquinone or Q10

Ubiquinone takes part in the mitochondrial transport of electrons. No effect has been experimentally shown on tissue function and performance in horses.

Carnosine

Carnosine normally accounts for about 30% of physical-chemical buffering system of muscle fibres II. It is involved in the regulation of intracellular acid-base balance. But the mechanisms that are implicated in synthesis and metabolism remain unknown. Even supplementation with histidine and/or β-alanine may not significantly elevate carnosine concentration in muscles. In contrast to man, no statistical effect has been shown upon performance in horses. In addition, deleterious effects, such as paresthesia, have been observed in man.

Sodium bicarbonate

Sodium bicarbonate is sometimes administered to counterbalance the decrease of intracellular pH resulting from lactate production and subsequent H^+ released during exercise that promote muscle fatigue. Significant effects have not been shown experimentally or in field conditions on race performance. In man, results are contradictory. This practice is even prohibited in several countries.

Ribose

Muscle contraction would be limited in horses following several very heavy exercise bouts as muscle ATP concentration decreases due to adenine nucleotides loss. Only 30% of nucleotides would be restored within 5 hours. As a result, temporary lack of nucleotides (purine) related to limited formation of pyrophosphate phosphoribosyl from pentose and ribose would occur. Efficiency of ribose studies in man has not yet been shown. There are no published data for horses.

6.6.1.2 Nitrogen metabolism

Supplementation with amino acids might be relevant in two situations: healing of muscle tissue damages or to delay fatigue. Other situations can be solved with well-balanced and adapted feed allowances combined with good training to prevent energy deficits and ensure muscle development.

Relevance of branched amino acids supplementation (leucine, isoleucine and valine) has not yet been shown nor have any ergogenic effects or restoration of tissue damages. Aspartic or glutamic acids would stimulate ATP production, but the effects of these amino acids has never been shown.

6.6.2 Antioxidants

Antioxidants are increasingly studied in the athletic horse as in man to reduce oxidative stress effects, which are so-called reactive oxygen species or ROS. They could be involved in recurrent airway obstruction and in some osteoarticular disorders.

Oxygen of antioxidants or free radicals (NO, O_2^-, OH) is more reactive than that of air because these molecules contain one more electron in their external orbit which increases reactivity with other molecules. Oxidants are produced in the respiratory tract as much during the inflammatory process as through exercise (exogenous oxidants) via over-regulation of mitochondria metabolism (endogenous oxidants). Pro-oxidative enzymes such as NADPH oxidase (nicotine adenine dinucleotide phosphate oxidase) or myeloperoxidase produce with metallic ions support (copper or iron), large quantities of oxidants, which peroxide lipids of cellular membranes (ROOH) of microorganisms that attack the organism, and also oxidise their proteins which act as receptors. In the early stage oxidants are protectors of the organism as they destroy microorganisms. Finally, it is the unbalance between oxidants and antioxidants which leads to oxidative stress.

Oxidative stress is normally countered in the organism with ion-dependant enzymes such as: glutathion peroxidase (selenium), superoxide dismutase (copper, zinc, manganese) and catalase (iron), and ion-dependant antioxidants such as: ceruloplasmin (copper) and ferritine (iron). Exogenous antioxidants are also used: vitamin E (α tocopherol), vitamin A (β carotene), vitamin C (ascorbic acid), lutein, lycopene, proteoglycans, ubiquinone.

Two issues arise: when does the imbalance of the oxidants/antioxidants ratio become pathologic? What are the reliable markers of the balance providing there may be breed, sex, age of horse, of time and feeding, which can only be interpreted by an expert? Supplementation should reduce the chronic inflammatory phenomena that are detrimental to organism homeostasis without limiting specific defences of the horse's airways in the presence of environmental pathogenic agents. Toxicity tolerance limits must be recognised when supplying of some elements (Chapter 2).

6.6.3 Vitamins

Vitamins allowances that are proposed in tables of recommended allowances already include the specific situation of the heavily exercised horse in respect of available knowledge (Section 6.3.4.5 'balance of ration'). Secondary detrimental effects can occur by excessive supplementation.

6.6.4 Other supplements

Several proposed supplements are in use, such as dimethylglycine, which is the active principle of pangamic acid; dimethylsulfoxide, the octacossanol, which is an alcohol of wheat germ oil; superoxide dismutase, which is likely destroyed during digestion. No nutritional benefit has been shown in horse to date.

Gamma oryzanol is mixture of feruclic acid ester, of sterol and triterpene alcohol extracted from rice bran. No anabolic effect has been shown in any animal species. In addition, the additive is prohibited by European regulation (EC, 2003; Regulation 1831/2003, Appendixes 3 and 4, Annex additives list, Revision 27). Interest in phyto products is increasing in the horse world, as in man, regarding expected aromatic effects on feeds and benefits on health (discussed in Chapter 9), or sometimes as ergogenic aids. To date no effect has been shown in horses.

6.7 Feeds contaminants and doping

Feeding contaminated feeds and doping are completely different issues (Bonnaire *et al.*, 2008). Unfortunately, a large number of 'positive cases' officially are reported by racing or equestrian authorities all over the world. They can be attributed to prohibited substances inadvertently found in the horse's feed. These are mentioned in Chapter 9.

For a better understanding of feed contamination issues it is necessary to refer to regulations and definition of prohibited substances. Substances capable at any time of acting on one or more of the following mammalian body systems:

- the nervous system;
- the cardiovascular system;
- the respiratory system;
- the digestive system;
- the urinary system;
- the reproductive system;
- the musculoskeletal system;
- the blood system;
- the immune system except for licensed vaccines against infectious agents;
- the endocrine system: endocrine secretions and their synthetic counterparts, masking agents.

The substance itself or a metabolite of the substance or an isomer of the substance or an isomer of a metabolite is a prohibited substance. The finding of any scientific indicator of administration or other exposure to a prohibited substance is also equivalent to the finding of the substance. As a result, any drugs which act on any mammalian body system must be considered as prohibited substance at any concentration.

The official rules which govern doping for racing and equestrian sports are displayed on web sites: http://www.horseracingfed.com and http://www.fei.org, respectively.

Two examples are given to illustrate the issue. As early as 1990's theobromine was detected in urine samples of horses fed with feeds contaminated with cacao grains or their by-products (husks). Morphine positive complex cases were detected in horses fed with commercial dehydrated alfalfa-based compound feeds contaminated by wild poppies from different species. The process of contamination was investigated. It was established that alfalfa and poppies, dedicated to pharmaceutical laboratories, were dehydrated in the same funnel without any decontamination step between the two batches of materials.

Of course many other drugs can also be detected (listed in Table 9.7, Chapter 9). This list should also contain bufotenine and dimethyltryptamine (DMT), codeine, hordeine, lupanine, which are present in horse environments. These substances are classified in the grey zone with the exception of bufotenine and DMT. These last two substances are well-known to exhibit pharmacological effects that are prohibited by some racing authorities or by equestrian sports federations. This issue is becoming an international matter as horses are travelling across borders and manufactured feedstuffs are sold worldwide.

The only efficient method of avoiding these inadvertent positive cases is to control feed ingredients used to formulate compound feeds and compound feeds too. Feed manufacturers are in charge of these controls which can be carried out internally or by external laboratories. In both cases the laboratories should be knowledgeable and harmonised with the official detection limits. Control can be carried out by an accredited laboratory for example: Laboratoire des Courses Hippiques (LCH, Verrière le Buisson, France).

Contamination thresholds are regularly discussed by international reference laboratories, including LCH, with regulatory authorities of racing (European Horseracing Scientific Liaison Committee) and equestrian sports (AFLD, FEI).

Similarly, detection thresholds of prohibited substances or their metabolites in urine and blood should also be defined to adopt and harmonise a maximum level of feed contamination which will be the reference values for the quality controls already in place with feed manufacturers.

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Chapter 7. Fattening horse for meat

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Horse meat is consumed in several European countries, mainly Belgium, France, Italy, Slovenia, Spain, and marginally Germany and Switzerland. In France, yearly consumption averages 0.3 kg per inhabitant, e.g. 18,000 tons (ECUS, 2013). Most of this tonnage is imported as carcasses or even boneless meat mainly from countries that are not consumers: North America, Argentina, and from some European countries as well. These importations are basically culled horses of light breeds. In France, these importations cost about 87 million Euros yearly, whereas there are 80,000 draft horses (e.g. 8% of the equine population; ECUS, 2013) which are grazing grassland on hilly or mountainous areas that are under-grazed by ruminants (Chapter 3 and 10). Only a marginal percentage of this draft horse population is used for work.

In France, systems of horse meat production have been studied. They are implemented in the field using foals from the main French draft breeds (Ardennaise, Boulonnaise, Bretonne, Comtoise and Percheronne), weaned at 6-7 months of age in autumn. Different types of young horses can be fattened at weaning or older ages either on pasture or in feedlot. Several systems of production have been designed using different growth curves whose biological basis has been described in Chapter 5.

7.1 Different production systems

According to the slaughter age of the horse, different systems have been studied (Table 7.1).

7.1.1 Heavy foal

Foals, born early in the year and/or born from large body sized mares, are supplemented with concentrates from 4 months of age while they are still nursing and grazing late summer regrowth of grassland pasture. The foal is slaughtered at 380-420 kg live bodyweight (LBW) (Figure 7.1) and produces 220-240 kg carcass weight. The ratio between hot carcass weight (HCW) and empty bodyweight (EBW) so called true carcass yield is high HCW/EBW: 67-69% and the body fat is good (internal thoracic fat weight: 3-4 kg)

7.1.2 Weanling: 10-12 months

The foal is weaned at an average 350 kg BW. The young horse is exclusively fattened in feedlot. Average daily gains ranges between 1000 to 1,400 g which is very close to the genetic potential of the breeds. The young horse is slaughtered at 450-500 kg BW (Figure 7.1) and produces 270-300 kg carcass weight (CW). The true hot carcass yield is very high 70-71% and body fat is very good (Table 7.2). Meat is still pale pink and adequately tender (Figure 7.2).

Young fillies that are not included as the replacements in the herd are fattened. But the proportion of concentrate in the ration should be limited to 50% with hay-based diet and 30% with maize silage diets to prevent any excessive fattening.

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Table 7.1. Main production systems (Martin-Rosset and Trillaud-Geyl, 2015; Martin-Rosset *et al.*, 1985).

Age of animals at slaughter(months)	Feeds	Systems	Area of production
6 to7[a]	milk + grass + concentrate (60-80 days before weaning)	heavy foal	forages production
10 or 15[b]	good quality forages (free choice) + concentrate (35-60% of diet)	intensive	forages and grain production feedlots
12 to 18[a]	grazing good grass + cereals grain end of summer (during 2 months)	moderately intensive	forage production
18 to 24[c]	forages: coarse (free choice), good quality (limited amount) + concentrates (10 to 20% of diet)	moderately intensive	forage production
6 to 30[a]	forages: good quality (1st winter) and average quality (2nd winter) free choice or by-products of forages and grains production: free choice with minimum of forage (2nd winter) + concentrate (15% of diet: 1st winter and 5%of diet: 2nd winter) grazing average quality grass	extensive	forage production marginal lands

[a] Finished on pasture.
[b] Fattened in feedlot.
[c] Finished in feedlot.

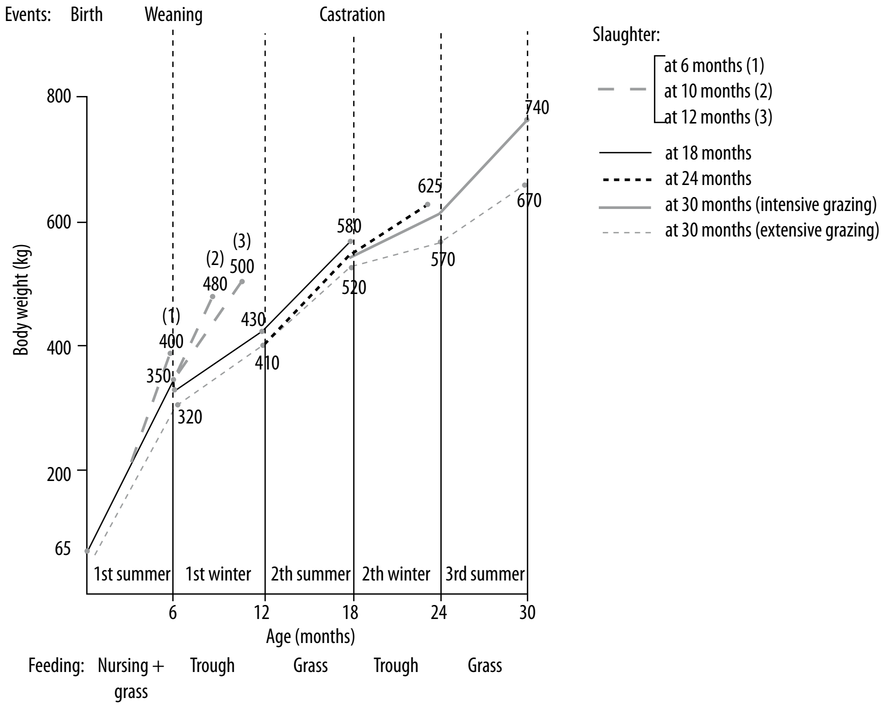

Figure 7.1. Variation of bodyweight of young horses in the main production systems.

Table 7.2. Slaughter characteristics of young horses between 12 to 30 months (Martin-Rosset and Trillaud-Geyl 2015; Robelin *et al.*, 1984).

		Bodyweight (kg)	Empty bodyweight[1] (kg)	Weight of hot carcass (kg)	True carcass yield[2] (%)	Body fat:flare fat[3] (kg)	Anatomical composition of carcass			Muscle/bone
							Muscles (%)	Fat (%)	Bone (%)	
Age (months)	12	483.2	439.6	313.4	71.2	3.86	70.1	10.9	15.6	4.48
	18	572.7	474.0	328.9	69.3	2.97	71.8	9.4	16.1	4.46
	24	626.8	539.6	382.7	70.9	5.94	69.8	12.9	14.9	4.69
	30	735.3	622.0	440.8	70.9	9.86	69.0	14.2	14.5	4.81
Sex[4]	male	628.6	535.5	377.2	70.4	5.46	70.7	11.0	15.6	4.56
	female	558.3	485.0	343.6	70.8	5.28	69.7	12.5	15.1	4.63
Breeds	Ardennaise	599.8	516.9	362.6	70.1	6.97	69.6	12.9	14.9	4.69
	Boulonnaise	583.1	498.5	352.3	70.6	3.99	71.6	9.2	16.4	4.38
	Bretonne	568.9	480.9	338.9	70.5	4.19	70.9	10.9	15.5	4.57
	Comtoise	570.3	492.3	347.0	70.4	7.15	68.5	14.3	14.3	4.80
	Percheronne	658.9	572.0	407.1	71.7	4.37	70.9	10.8	15.7	4.52

[1] Empty bodyweight = live bodyweight – weight digestive tract.

[2] Hot carcass weight/empty bodyweight.

[3] Flare fat = internal fat located on the internal abdominal surface and under the diaphragm.

[4] All merged ages (12 to 30 months).

7.1.3 Yearling horse: 18 or 24 months

Following weaning, growth is moderate during the winter because the yearling is fed only limited amounts but during summer grazing compensatory growth is high (Figure 7.1). The yearling is raised to 18 months of age from a weaned foal of 330 kg BW minimum. During the winter, average daily gains range only within 600 to 800 g but elevate to 900 to 1,100 g while grazing good grassland in the summer. The yearling is not gelded at 12 months. Finishing during the last two grazing months is done with supplementation of cereals grains. It is slaughtered at 550-580 kg BW (Figure 7.1) and 330-350 kg CW. True hot carcass weight yield is lower than at 12 months and body fat is limited (Table 7.2). The meat is getting to be red and is still somewhat tender (Figure 7.2).

The long yearling is raised until 22-24 months from a foal whose bodyweight at weaning is lower than 330 kg BW, or from an animal which experienced low growth during grazing. It is finished at through during the second winter between 18 to 22 or 24 months. It is slaughtered at 600-650 kg BW (Figure 7.1) and 360-390 kg CW. True hot carcass weight yield is higher than at 18 months and body fat as well (Table 7.2). The meat is more red and a little more tender as well (Table 7.2).

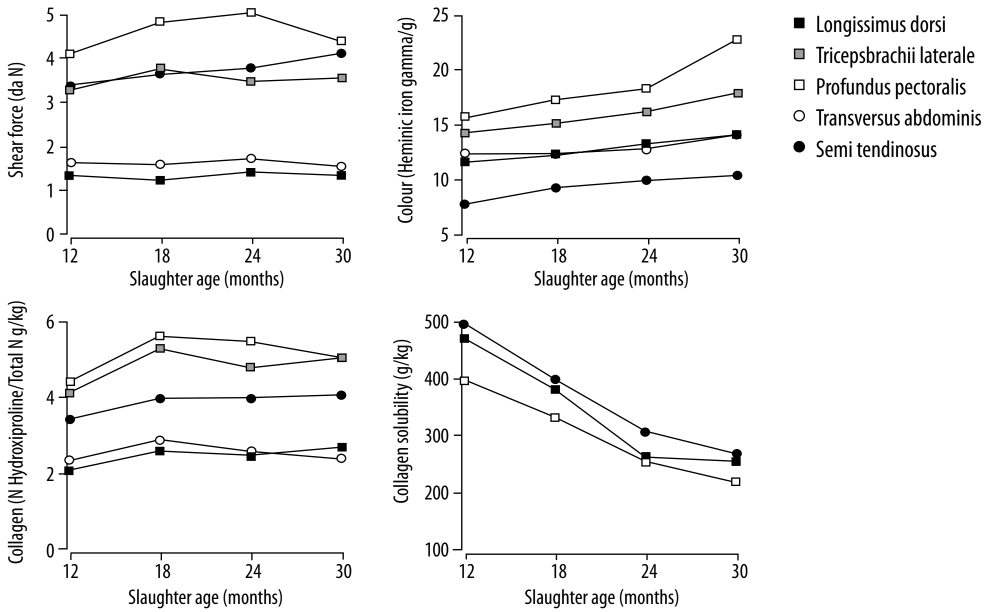

Figure 7.2. Variation of physical-chemical characteristics of meat with age in horse (adapted from Boccard *et al.*, 1976).

7.1.4 Young horse: 30 months

Daily gains of these animals are often limited during the 1st (500-700 g) and 2nd (200-400 g) winter following weaning. Resulting compensatory growths are very high during the 1st (700-800 g) and the 2nd (600-700 g) summers (Figure 7.2). They are castrated at 18 months. They are slaughtered at 670-740 kg BW and 400-430 kg carcass. True hot carcass weight yield is high and body fat is very good (Table 7.2).

Fillies of 24 months which had been included into the replacement herd but had been removed because fertilisation at 2 years of age has not been successful can be involved in this production system to be slaughtered at 30 months of age. Similarly, the young mare which foaled at 3 years of age but then has not conceived successfully again, can be finished for slaughter at 40 months of age.

7.1.5 Breeds

Growth rates and carcass weight in these production systems are not statistically different between the main draft breeds. In contrast, the amount of body fat at slaughter is different (Table 7.2).

7.2 Nutrients requirements and recommended allowances

The nutrients requirements for fattening the young horse depends on bodyweight, age of animal and daily gain because the proportion of lipids in body mass gain increases with these measurements (Chapter 5). Energy requirements of fillies are higher than those of colts at the same average daily gain.

Requirements were determined in numerous feeding trials that were carried out at IFCE with animals of different ages, bodyweight and average daily gain and breeds fed various diets. The recommended allowances correspond to the total requirements for maintenance and growth and/or fattening.

Tables of recommended allowances are displayed for two adult body sizes: 700 and 800 kg (Table 7.3 and 7.4). Only animals which are exclusively fattened or finished in feedlot with high energy diets are given in these tables. Recommended allowances for growing animals during the winter to be finished on pasture and slaughtered at 18 or 30 months or fillies held as replacements are displayed in Table 5.5 and 5.6 in Chapter 5.

Recommended feed allowances can be verified following evaluation of the ration using Table 2.1 in Chapter 2 and the calculation method described in Chapter 13.

7.3 Ration formulation and evaluation

7.3.1 Winter feeding: choice of diets

The weanling, slaughtered at 10 or 12 months, is fattened with a very high energy diet, based on high nutritive value forages fed free choice (maize silage harvested at minimum 35% DM or grass hay very early harvested: 1st cycle early heading) and supplemented with 35 to 60% concentrate according to the age and forage offered maize silage or hay respectively. Wrapped grass silage with a minimum 50% DM can be fed as well.

The yearling, slaughtered at 18 months, is wintered between 6 and 12 months with a forages-based diet of good to average nutritive value fed free choice; maize silage with a minimum of 30% DM, grass silage that is pre-wilted at 35% DM or hay that is mature but properly harvested (1st cycle – full heading). Forages-based diets are supplemented with 5 to 20% concentrate according to the quality of forage fed (Table 7.5).

The long yearling, slaughtered at 24 months, is finished in a feedlot during the winter with a good quality forages-based diet fed free choice and supplemented with 25% concentrate (Table 7.5).

Finally, the young horse, slaughtered at 30 months, is fed during the three successive winters with a forages-based diet of average quality (grass hay late harvested, 1st cycle, heading) and straw fed both free choice and supplemented with 5 to 10% concentrate according to age and type of forages offered (Table 7.5).

In all systems, concentrates that are used to supplement the diets, can be composed of variable proportions of cereals grains (barley or corn), oils or legumes seeds meals, preferably soybean meal, for young horses slaughtered at 10 or 12 months, and peanut, lupin or horse bean meals for other young horses slaughtered at later ages.

Table 7.3. Recommended daily nutrients allowances and intake allowances during fattening period in young draft horse of adult bodyweight of **700 kg**.

Age[1] (months)	Average bodyweight[2] during period (kg)	Bodyweight gain (g/d)	Daily nutrients allowances																		Dry matter intake[3] (kg)
			UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
7-10	420	1,200-1,300	8.2	910	79	59	40	8	10	34	30	90	450	1.8	1.8	360	450	1.8	31,100	5,400	720	8.0-10.0
7-10	500	1,400-1,600	9.2	1,080	94	71	48	10	12	40	35	98	488	2.0	2.0	390	488	2.0	33,700	5,900	780	9.0-10.5
7-12	450	900-1,000	6.9	750	73	54	37	8	10	36	31	90	450	1.8	1.8	360	450	1.8	31,100	5,400	720	8.0-10.0
18-24	620	500-600	7.3	600	63	62	42	10	13	50	41	115	575	2.3	2.3	460	575	2.3	40,300	5,800	690	10.5-12.5

[1] Slaughter age.

[2] Median bodyweight during the period.

[3] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 7.4. Recommended daily nutrients allowances and intake allowances during fattening period for young draft horse adult bodyweight of **800 kg**.

Age[1] (months)	Average bodyweight[2] during period (kg)	Bodyweight gain (g)	Daily nutrients allowances																		Dry matter intake[3] (kg)
			UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (mg)	Zn (mg)	Co (mg)	Se (mg)	Mn (mg)	Fe (mg)	I (mg)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
7-10	470	1,300-1,400	9.2	980	85	65	44	9	11	38	33	100	500	2.0	2.0	400	500	2.0	34,500	6,000	800	9.0-11.0
7-10	550	1,500-1,700	10.0	1,150	100	76	52	11	13	44	39	108	538	2.2	2.2	430	538	2.2	37,100	6,500	645	10.0-11.5
7-12	500	1,000-1,100	7.8	820	71	60	41	9	11	40	34	100	500	2.2	2.2	400	500	2.2	34,500	6,000	800	9.0-11.0
18-24	680	600-650	8.0	670	58	69	46	11	14	54	44	125	625	2.5	2.5	500	625	2.5	43,800	6,300	750	11.5-13.5

[1] Slaughter age.

[2] Median bodyweight during the period.

[3] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 7.5. Winter regimen, grazing and growth performed (Martin-Rosset and Trillaud-Geyl, 2015; Martin-Rosset *et al.*, 1985).[1]

Age at slaughter	Regimen			Average daily gain (g/d)
	Basal diet[2]	Concentrate		
		Type	kg	
6-7 months	mare's milk + grass	cereals grains (maize, barley) + soybean meal	2 from3 months of age	1,600-1,800 (birth – weaning)
10 months	early harvested hay, or maize silage (≥30% DM)	cereals grains (maize, barley) + soybean meal	5-5.5	1,100-1,400
12 months	early harvested hay or maize silage (≥30% DM)	cereals grains (maize, barley) + soybean meal	3	1000-1,300
	grass silage:			
	pre-wilted (≥28% DM)		3.5-4	900-1,100
	pre-wilted (≥35% DM)		3	900-1,200
18 months	winter			
	late harvested hay	cereals grains (maize, barley) or peanut meal	1-2	500-700
	maize silage (≥25% DM)		1	
	grass silage: pre-wilted (≥28% DM)		1-2	
	summer			
	grass + 80 nitrogen units /ha; rotation – electric fence; 2.5 animal/ha with or without associated cattle	ground maize	3 (last 60 days of grazing)	800-1000
24 months	1st winter	see 18 months but without concentrate in summer		600-800
	1st summer see 18 months			
	2nd winter			
	maize silage (≥25% DM)	cereals grains (maize, barley) + soybean or peanut meals	3.0	800-900
	maize silage (≥35% DM)		2.0-2.5	
30 months	1st winter	see 18 months but without concentrate in summer		500-700
	1st summer see 18 months			800-1000
	2nd winter			
	late harvested hay	cereals grains (maize, barley) + soybean or peanut meals	0.5-1	200-300
	late harvested hay (50% of DMI) + straw (35% of DMI)		1-1.5	
	maize silage (≥25% DM)		0.5-1	
	grass silage (≥28% DM)		1-1.5	
	2nd Summer			
	see 18 months	without concentrate		600- 700

[1] During experimental periods following adaptation to fattening diets.

[2] Free choice; DMI = dry matter intake; DM = dry matter.

7.3.2 Main points on grazing management

The animals are grazing for 140 to 190 days depending on the years and lowland regions with natural grasslands fertilised with 60 to 80 nitrogen units per hectare in two spreadings (Chapter 10). The young horses can be managed alone or together with beef cattle of 1 or 2 years old steers or breeding heifers associated using a ratio 1/1 or 1/3 according to grassland productivity whether it be high or moderate, respectively.

The young horse slaughtered at 18 months should definitely be supplemented daily with an average of 2 kg of ground maize fed free choice during the last two months of grazing season to reach a minimum body condition (Table 7.1).

The young horse slaughtered at 30 months does not need any supplementation during grazing seasons when growth is well managed from weaning because body fat percentage increases with bodyweight (Table 7.2). However, colts should be castrated. Fillies, which are held for reproduction, can be raised using this system as they get fat more easily (Table 7.2).

7.4 Practical advices for feeding management

7.4.1 Selecting animals

In addition to the bodyweight criteria previously mentioned in the first paragraph, animals should be bought with an average body condition and sound legs (without any signs of arthritis signs). They should be healthy: avoid animals that have a cough, or have nasal discharge and swollen glands under the lower jaw. Animals should be free external parasites (lice, ringworm, etc.) or show any sign of internal parasites (*Parascaris, Strongylus, Gasterophilus),* such as diarrhoea more or less profuse ('the squirts'), a distended belly and ruffled tail hairs (from rubbing) or partially hair loss around the tail head.

7.4.2 Transport

It is preferable to have short transport without transit for animals bought on fairgrounds. Animals should be watered before and after transport or even during when the transport is long. The presence of air currents during transport can be responsible for causing respiratory disorders. Transport of horses should also be in compliance with the official regulations for animal transport.

7.4.3 Adaptation period

This period lasts 3 weeks. The objective during this period is to reduce weaning stress, adapt to the change of environment and to address health issue (mainly deworming). Animals should be allocated to homogenous groups of 6-7 individuals maximum by age, bodyweight, body condition and health, and social behaviour (Chapter 15).

Animals should be managed on straw bedding in loose housing. Minimum surface per animal should be 5-6 m^2 for 6-12 months of age and 7-8 m^2 for 18-24 months of age. The width necessary for feed trough access per animal should be 0.60-0.80 cm respectively for these two classes of age.

During this period, the animals should be fed with good quality hay (1st cycle, heading) supplemented daily with 2 kg of concentrate per animal. Prophylactic treatments should be implemented (deworming then vaccination).

Animals should be increasingly adapted to their fattening diet: hay is replaced by silage for example during 1 to 3 weeks according to the age of animals, type of forage (silages vs. hay) and the expected final amount of concentrate.

7.4.4 Fattening period

Type and composition of the diet should be as steady as possible. Therefore, having sufficient feed supply should be planed. Rations should be distributed in two meals at a fixed time every day. Forage should be offered prior to the concentrate to prevent greedy animals from consuming too much concentrate. The amount of feeds offered daily should be in accordance to goals for growth and in line with the amount consumed during the previous two days. Deworming again in the middle of winter is recommended and effective.

7.4.5 Body condition

Body condition should be monitored during the fattening period using the method of INRA/HN/IE (1997) and Martin-Rosset *et al.* (2008) described in Chapter 2 to adjust feeding and to meet the expected body condition score and related fat percentage of the carcass according to slaughter age (Table 7.2).

At slaughter, fat condition is evaluated using the weight of flare fat, e.g. internal fat located on the internal abdominal surface and under the thorax (Table 7.2), or just using the visual appraisal of the surface and thickness of fat deposits.

Fat content is significantly higher in breeds of small and average body size (Table 7.2). At the same empty bodyweight (without weight of digestive tract) the fat percentage in the carcass is 2 to 4% higher in Ardennaise, Bretonne and Comtoise breeds without resulting any difference in true carcass yield (Table 7.6). Therefore, these breeds are earlier maturing than large size breeds (Boulonnaise and Percheronne) because they reach the same fat percentage in the carcass at a lower bodyweight: -11 to -98 kg (Table 7.7). Carcass weight is lower as well in spite of the true carcass yield not being different.

Table 7.6. Carcass weight and composition of young horses of different breeds compared at same empty bodyweight (504.8 kg) (Martin-Rosset *et al.*, 1980).

Breed	Weight of hot carcass (kg)	True carcass yield (%)[1]	Fat weight of the carcass (kg)	Fat in the carcass (%)	Muscles weight of the carcass (kg)	Muscles in the carcass (%)
Ardennaise	353.6	70.0	42.5	12.0	246.7	69.8
Boulonnaise	357.1	70.7	30.5	8.5	256.0	71.7
Bretonne	356.0	70.5	38.3	10.8	252.0	70.2
Comtoise	356.5	70.6	50.7	14.2	255.3	68.2
Percheronne	357.2	70.7	33.2	9.3	255.3	71.5

[1] Hot carcass weight/empty bodyweight.

Table 7.7. Carcass weight and composition of young horses of different races compared at the same total fat deposits (10.4% of empty bodyweight) (Martin-Rosset *et al.*, 1980).

Breed	Empty bodyweight (kg)[1]	Weight of hot carcass (kg)	True carcass yield (%)[2]	Muscles weight of the carcass (kg)	Muscles in the carcass (%)
Ardennaise	507.8	355.2	69.8	247.9	70.4
Boulonnaise	518.7	368.6	71.0	261.7	69.9
Bretonne	486.0	343.1	70.6	242.2	70.5
Comtoise	471.3	330.1	70.0	231.1	70.2
Percheronne	579.5	413.3	71.3	294.7	70.3

[1] Empty bodyweight = live bodyweight – weight digestive tract.
[2] Hot carcass weight/empty bodyweight.

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References quoted through the text are only listed; for other references which are supporting the chapter, see 'Further reading'.

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Chapter 8. Ponies, donkeys and other cases of interest

William Martin-Rosset and Jean-Louis Tisserand†

Several types of equidae are discussed in this chapter. Although they are of high concern, the amount of scientific material was too limited to give them each specific chapters. For both ponies and donkeys, their physiologies and/or metabolisms are different from those of horses. Hence, they should not be combined with the horse information. For the other cases of interest, such as horses maintained on pastures or aged horses, that have potential for raising societal issues, it seems more relevant to focus on these cases separated from general cases in the scope of a single chapter.

8.1 Ponies

8.1.1 Introduction

The pony population has exploded with the increase in leisure riding in industrialised countries in the last three decades. Shetland ponies are routinely used in riding schools to educate very young riders, and then medium and large ponies are ridden by teenagers for competitions. Hence, ponies represent a large proportion of equine population in riding schools, which is causing an increase in pony production. Unfortunately, feeding the ponies is still very empirical and very often extrapolated from knowledge in horses, which is partially wrong. Thus, specific information is provided in this chapter to promote new guidelines for feeding ponies.

8.1.2 Nutritional status

Owing to the body size and low cost of maintenance, the gelding pony has been mainly used as a 'small horse' to study the physiology and metabolism of equines, but rarely to evaluate nutrient requirements corresponding to the different nutritional states: from pregnancy to exercise. The pony is both similar and different from the horse. The pony is subject to the same general biological laws as the horse (Chapter 1), but some differences should be pointed out and then taken into account to arrive at relevant recommended allowances.

8.1.2.1 Ingestion and digestion

Intake and digestion of forages (Cuddeford, 1992; Drogoul, 2000a,b; 2001; Hale and Moore-Colyer, 2001; Hyslop and Calder, 2001; Hyslop *et al.*, 1998; Moore-Colyer and Longland, 2000; Morrow *et al.*,1999) or grains (Hintz *et al.*, 1971; McLean *et al.*, 1998, 1999) are similarly affected in ponies as in horses (see Chapter 12) by the types of forages or grains, feed processing and forage/concentrate ratio.

The rate of ingestion of feeds expressed in grams/kg DM/min is much slower in the pony than in the horse fed the same diet: 20 to 48% for very good or low quality hays, respectively. This difference leads to a slightly higher digestibility of feeds in the pony, on average +2 points for forages, e.g. 4 to 5% for hay digestibility, but also a much higher energy expenditure for chewing, +50% compared to the horse

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(Vermorel *et al.,* 1997). Energy expenditure of ingestion in the pony and horse represents on average 15 and 10% of metabolisable energy of hay consumed, respectively (Vermorel and Mormed, 1991).

8.1.2.2 Metabolism

Energy expenditure of the resting pony measured by indirect calorimetry at INRA is only 73 kcal net energy (NE)/kg $BW^{0.75}$, which is 16% lower than that measured in the horse at 83 kcal/kg $BW^{0.75}$ determined under the same conditions (Vermorel *et al*., 1997). Protein expenditure, which is linked to energy expenditure, decreases in the same proportion. Interestingly, protein expenditure measured at INRA in the pony fed at maintenance is lower as well, because the retention rate is on average 10% higher than that measured in the horse in the same experiment.

8.1.2.3 Requirements

Experimental data on maintenance, foetal growth, milk yield, growth and work in the pony are scarce compared to horses (Hintz *et al*., 1970-1986; Jordan, 1972-1983; Pagan *et al*., 1981-1986; Vermorel *et al*., 1991-1995; Olsman *et al*., 2003). However, using this limited data, after checking to see if they are consistent with general biological laws and in relation to what has been measured in horse, a reliable range of requirements has been determined in the pony. Maintenance requirement is evaluated to be 0.0333 UFC/kg $BW^{0.75}$. The protein/energy ratio set for the horse (65 g MADC/UFC) is used for the pony at maintenance and work, even though the retention rate is higher in the pony than in the horse. For work *sensu stricto* (strictly speaking), requirements in the pony are determined from those measured in the horse, but, of course, relative to the pony's weight. Intake is similarly determined. Requirements for gestation, lactation and growth have been evaluated using experimental data obtained in the pony.

8.1.3 Recommended allowances

Two groups of ponies have been considered according to their body size and the difference from the horse:

- small ponies: 200 kg adult bodyweight;
- medium/large ponies: 300 and 400 kg adult bodyweight.

Bodyweight can be predicted using a simple model defined in the pony and described in Chapter 2 (Section 2.2.1.3).

Recommended allowances have been evaluated according to the same step-wise procedure used in the horse (Chapter 1 and 3 to 6). Recommended allowances are displayed according to the same models of tables as for the horse. However, no transfer is possible from tables devoted to ponies to tables dedicated to the horse and the reverse, of course, even if using a specific bodyweight for any calculation. In addition, no transfer can be implemented between the small pony and the medium/large pony, or the reverse, even if using a specific bodyweight because some metabolic factors are a little bit different. For example, there would be an over-valuation of the maintenance requirement relative to body size and activity if the medium/large pony were considered as half way between small pony and horse.

Work requirements are an exception. Allowances are established in the pony from those evaluated per hour of exercise in adult horse 500 kg BW + tack + rider (Chapter 6, Figure 6.11 and Table 6.8) taking into account specific bodyweight, tack and rider weight too.

Macromineral allowances are evaluated for the specific bodyweight of a pony using the models established in the horse for the different physiological states (Chapter 3 to 6). It is provided that bodyweight is a variable included in the models and there is not enough information in pony about the other variables (digestibility and retention) to make any reliable statements about the expected differences between the pony and the horse. Micromineral and vitamin allowances are evaluated from their concentration per kg DM intake displayed in Chapter 2, Table 2.1, and using the intake given for the small size pony (Table 8.1 to 8.3) and medium/large pony (Table 8.4 to 8.9).

8.1.3.1 Pony 200 kg bodyweight

The energy requirement at rest *sensu strict*o (maintenance) in the pony is 16% lower than in the horse, and the protein requirement as well. The energy requirement at maintenance increases:

- breeding period: +20% for the stallion involved in pasture breeding and only 10% during the quiescence period;
- working period: only +5%, because exercise is mostly light to moderate.

Similar overestimation is implemented for the protein requirement at maintenance as it is directly related to energy (65 g MADC/UFC). Recommended allowances are displayed in Table 8.1 to 8.3.

8.1.3.2 Pony 300 and 400 kg bodyweight

The energy requirement at rest *sensu strict*o (maintenance) in the pony is 10% lower than in the horse and for the protein requirement as well. The energy requirement at maintenance increases:

- breeding period: +25% for the stallion involved in hand breeding and only 15% during the quiescence period;
- working period: +10%, because exercise is more intensive than in the small pony.

Similar estimation is implemented for the protein requirement at maintenance as it is directly related to energy (65 g MADC/UFC). Recommended allowances are displayed in Table 8.4 to 8.9.

8.2 Horse maintained outside

During breeding or periods of use the horse may be subjected to variable climatic conditions which have repercussions that mostly affect energy expenditure. A description of these conditions should be done with advisable solutions for limiting their influence even though there have been few studies that focus on this topic that have been carried out.

Table 8.1. Recommended daily nutrients allowances and intake allowances for the pony adult bodyweight of **200 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake[6] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Maintenance																				
At rest[1]	1.7	122	11	8	6	3	4	16	10	34	170	0.6	0.6	136	170	0.6	11,100	1,400	170	3.0-3.8
Work																				
Temporary rest	1.8	129	12	9	7	4	5	18	11	37	185	0.7	0.7	148	185	0.7	12,000	1,500	185	3.4-4.0
Very light[2,3]	2.1	148	13	12	8	4	6	19	12	39	195	0.8	0.8	156	312	0.8	12,700	1,600	195	3.6-4.2
Light[2,3]	2.8	199	18	12	8	4	6	19	12	45	225	0.9	0.9	180	360	0.9	14,600	1,800	225	4.0-5.0
Moderate[2,3]	3.0	219	20	14	9	5	8	22	14	51	255	1.2	1.2	204	408	1.2	19,100	3,100	408	4.4-5.7
Intense[4]	2.8	205	19	16	12	6	10	27	16	45	225	0.9	0.9	180	360	0.9	16,900	2,700	360	4.0-5.0
Stallion																				
Non-breeding[5]	2.3	166	15	12	8	4	6	19	12	45	225	0.9	0.9	180	360	0.9	14,600	1,800	225	4.0-5.0
Breeding: service																				
Light	2.8	202	18	12	8	4	8	19	12	45	225	0.9	0.9	180	360	0.9	14,600	1,800	225	4.0-5.0
Moderate	3.1	223	20	14	9	5	8	22	14	51	255	1.2	1.2	204	408	1.2	19,100	3,100	408	4.4-5.7
Intense	3.5	252	23	16	12	6	8	27	16	45	255	1.2	1.2	204	408	1.2	19,100	3,100	408	4.4-5.7

[1] Without any specific work, gelding and mare are concerned by these allowances. For stallion, add 0.2 UFC and 15 g MADC.

[2] Pony is considered in riding school to work 2 hours a day (average observed in the field).

[3] Hacking: in the case of short hacking, very light work for 1 hour ride, and light work for 2 hours ride.

[4] Ponies are considered to work 1 hour daily (average observed in the field).

[5] Included daily 1 hour very light work for stallions box-stalled.

[6] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.2. Recommended nutrients allowances and intake allowances for the pony mare adult bodyweight of **200 kg.**[1]

Physiological status		Daily nutrients allowances																			Dry matter intake[2] (kg)
		UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Dry		1.7	122	11	8	6	3	4	16	10	37	185	0.7	0.7	148	296	0.7	12,000	1,500	200	3.2-4.2
Gestation																					
0-5 months		1.7	122	11	8	6	3	4	16	12	37	185	0.7	0.7	148	296	0.7	12,000	1,500	200	3.2-4.2
6th month		1.8	147	13	10	8	3	4	16	12	39	195	0.8	0.8	156	312	0.8	16,400	2,300	310	3.2-4.5
7th month		1.9	148	13	11	8	3	4	16	12	39	195	0.8	0.8	156	312	0.8	16,400	2,300	310	3.2-4.5
8th month		2.0	156	14	12	9	3	4	16	12	39	195	0.8	0.8	156	312	0.8	16,400	2,300	310	3.2-4.5
9th month		2.1	170	16	14	10	3	4	16	12	42	210	0.8	0.8	168	336	0.8	17,700	2,500	340	3.5-4.8
10th month		2.2	202	18	15	12	3	5	16	13	43	213	0.9	0.9	170	340	0.9	17,900	2,600	340	3.5-5.0
11th month		2.3	216	20	17	13	3	5	16	13	45	225	0.9	0.9	180	360	0.9	18,900	2,700	360	3.8-5.2
Lactation (kg milk/d)																					
1st month	6.0	3.5	386	31	22	20	4	5	19	31	58	290	1.2	1.2	230	460	1.2	20,300	4,900	290	5.0-6.6
2nd month	6.6	3.6	373	33	20	17	4	5	19	31	61	305	1.2	1.2	240	490	1.2	21,400	5,200	305	5.3-6.9
3rd month	6.9	3.3	352	32	20	17	4	5	19	30	61	305	1.2	1.2	240	490	1.2	21,400	5,200	305	5.3-6.9
4th month	5.8	3.1	290	30	16	14	3	4	18	26	58	290	1.2	1.2	230	460	1.2	20,300	4,900	290	5.0-6.6
5th month	4.4	2.7	219	26	14	12	3	4	18	26	53	265	1.1	1.1	210	420	1.1	18,900	4,500	265	4.5-6.0
6th month	4.0	2.6	210	24	14	12	3	4	18	26	44	220	0.9	0.9	176	350	0.9	15,400	3,700	220	3.8-5.0

[1] Bodyweight 24 h after a good foaling.

[2] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.3. Recommended nutrients allowances and intake allowances during growth of the pony adult bodyweight of **200 kg**.

Age	Average weight[1] during the period (kg)	Growth, bodyweight gain (g/d)	Daily nutrients allowances																		Dry matter intake[2] (kg)
			UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
6-12	109	220	1.9	217	19	13	9	2	2	9	8	30	150	0.6	0.6	120	150	0.6	10,400	1,800	240	2.5-3.5
18-24	164	100	2.3	133	14	15	10	3	3	13	11	40	200	0.8	0.8	160	200	0.8	13,100	2,000	240	3.5-4.0
30-36	186	50	2.5	125	13	16	11	3	4	15	12	45	225	0.9	0.9	180	225	0.9	15,800	2,300	270	4.0-5.0

[1] Median bodyweight during the period.

[2] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.4. Recommended daily nutrients allowances and intake allowances for the pony adult bodyweight of **300 kg**.

Utilisation	Daily nutrients allowances																			Dry matter intake[6] (kg)
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Maintenance																				
At rest[1]	2.4	173	16	12	8	5	6	24	15	51	255	1.0	1.0	204	255	1.0	16,600	2,000	255	4.5-5.7
Work																				
Temporary rest	2.6	190	17	13	9	6	7	27	17	55	275	1.1	1.1	220	275	1.1	17,900	2,200	275	5.0-6.0
Very light[2,3]	3.0	216	20	18	11	6	9	29	18	59	295	1.2	1.2	236	472	1.2	19,200	2,400	295	5.4-6.3
Light[2,3]	4.0	286	26	18	11	6	9	29	18	68	340	1.4	1.4	272	544	1.4	22,100	2,700	340	6.0-7.5
Moderate[2,3]	4.5	324	30	21	13	7	12	34	20	74	370	1.5	1.5	296	592	1.5	27,800	4,400	592	6.6-8.1
Intense[4]	4.2	302	28	24	17	9	15	42	24	68	340	1.4	1.4	272	544	1.4	25,500	4,100	544	6.0-7.5
Very intense[4]	4.7	338	31	27	19	11	25	56	32	68	340	1.4	1.4	272	544	1.4	25,500	4,100	544	6.0-7.5
Stallion																				
Non-breeding[5]	3.5	250	23	18	11	6	9	29	18	68	340	1.4	1.4	272	544	1.4	22,100	2,700	340	6.0-7.5
Breeding: service																				
Light	4.2	302	28	18	11	6	12	29	18	68	340	1.4	1.4	272	544	1.4	22,100	2,700	340	6.0-7.5
Moderate	4.5	324	30	21	13	7	12	34	20	74	370	1.5	1.5	296	592	1.5	27,800	4,400	592	6.6-8.1
Intense	5.1	367	33	24	17	9	12	42	24	74	370	1.5	1.5	296	592	1.5	27,800	4,400	592	6.6-8.1

[1] Without any specific work, gelding and mare are concerned by these allowances. For stallion, add 0.2 UFC and 15 g MADC.

[2] Pony is considered to work 2 hours a day in a riding school (average observed in the field).

[3] Hacking: in the case of short hacking, very light work for 1 hour ride, and light work for 2 hours ride.

[4] Ponies are considered to work 1 hour daily (average observed in the field).

[5] Included daily 1 hour very light work for stallions box-stalled.

[6] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.5. Recommended nutrients allowances and intake allowances for the pony mare adult bodyweight of **300 kg**.[1]

Physiological status		Daily nutrients allowances																			Dry matter intake[2] (kg)
		UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Dry		2.4	173	16	12	8	5	6	24	15	56	280	1.1	1.1	224	450	1.1	18,200	2,200	340	4.8-6.3
Gestation																					
0-5 months		2.4	173	16	12	8	5	6	24	18	56	280	1.1	1.1	224	450	1.1	18,200	2,200	340	4.8-6.3
6th month		2.6	211	19	15	12	5	6	24	18	58	290	1.2	1.2	232	464	1.2	24,400	3,500	460	5.1-6.5
7th month		2.7	212	19	16	12	5	6	24	18	58	290	1.2	1.2	232	464	1.2	24,400	3,500	460	5.1-6.5
8th month		2.9	224	20	18	12	5	6	24	18	58	290	1.2	1.2	232	464	1.2	24,400	3,500	460	5.1-6.5
9th month		3.0	245	22	20	15	5	7	24	19	61	305	1.2	1.2	244	488	1.2	25,600	3,700	490	5.4-6.8
10th month		3.2	292	27	22	17	5	7	24	19	64	320	1.3	1.3	256	512	1.3	26,900	3,800	510	5.4-7.3
11th month		3.3	313	29	25	19	5	7	24	19	68	340	1.4	1.4	272	544	1.4	28,600	4,100	540	5.7-7.8
Lactation (kg milk/d)																					
1st month	9.0	5.0	497	46	34	29	7	8	28	47	84	420	1.7	1.7	340	670	1.7	32,000	5,000	420	7.2-9.6
2nd month	9.9	5.1	549	49	30	25	6	8	28	47	87	435	1.7	1.7	350	700	1.7	33,100	5,200	435	7.5-9.9
3rd month	9.6	4.8	519	48	29	24	6	8	28	46	87	435	1.7	1.7	350	700	1.7	33,100	5,200	435	7.5-9.9
4th month	8.7	4.5	425	45	24	20	6	7	27	40	81	405	1.6	1.6	320	650	1.6	31,000	4,900	405	7.2-8.9
5th month	6.6	3.9	318	38	21	17	5	7	27	39	73	365	1.5	1.5	290	580	1.5	27,700	4,400	365	6.7-7.9
6th month	6.0	3.8	305	36	20	16	5	7	27	38	65	325	1.3	1.3	260	520	1.3	24,700	3,900	325	5.7-7.2

[1] Bodyweight 24 h after a good foaling.

[2] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.6. Recommended nutrients allowances and intake allowances during growth of the pony adult bodyweight of **300 kg**.

Age (months)	Average weight[1] (kg)	Growth, bodyweight gain (g/d)	Daily nutrients allowances																			Dry matter intake[2] (kg)
			UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Growth – husbandry																						
6-12	164	320	2.7	304	27	19	13	3	4	13	11	45	225	0.9	0.9	180	225	0.9	15,500	2,700	360	4.0-5.0
18-24	246	130	3.4	203	21	22	15	4	5	20	16	55	275	1.1	1.1	220	275	1.1	19,300	2,800	330	5.0-6.0
30-36	279	70	3.7	192	20	24	16	4	6	22	18	60	300	1.2	1.2	240	300	1.2	21,000	3,000	360	5.5-6.5

[1] Median bodyweight during the period.

[2] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.7. Recommended daily nutrients allowances and intake allowances for the pony adult bodyweight of **400 kg**.

Utilisation	Daily nutrients allowances																			Dry matter
	UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	intake[6] (kg)
Maintenance																				
At rest[1]	1.7	230	21	16	11	6	8	32	20	69	345	1.4	1.4	276	345	1.4	22,400	2,800	345	6.0-7.6
Work																				
Temporary rest	3.5	252	23	18	12	7	9	35	22	72	360	1.4	1.4	288	360	1.4	23,400	2,900	360	6.5-7.8
Very light[2,3]	4.0	288	26	24	15	8	12	35	24	78	390	1.6	1.6	312	624	1.6	25,300	3,100	390	7.2-8.4
Light[2,3]	5.4	389	35	24	15	8	12	35	24	90	450	1.8	1.8	360	720	1.8	29,300	3,600	450	8.0-10.0
Moderate[2,3]	6.0	432	39	28	17	9	16	44	27	98	490	2.0	2.0	392	784	2.0	36,800	5,900	784	8.8-10.8
Intense[4]	5.6	403	37	32	23	12	20	53	31	90	450	1.8	1.8	360	720	1.8	33,800	5,400	720	8.0-10.0
Very intense[4]	6.3	455	41	36	25	15	33	74	42	90	450	1.8	1.8	360	720	1.8	33,800	5,400	720	8.0-10.0
Stallion																				
Non-breeding[5]	4.6	334	30	24	15	8	12	35	24	90	450	1.8	1.8	360	720	1.8	29,300	3,600	450	8.0-10.0
Breeding: service																				
Light	5.6	403	37	24	15	8	15	35	24	90	450	1.8	1.8	360	720	1.8	29,300	3,600	450	8.0-10.0
Moderate	5.8	418	38	28	17	9	15	44	27	98	490	2.0	2.0	392	784	2.0	36,800	5,900	784	8.8-10.8
Intense	6.7	484	44	32	23	12	15	53	32	98	490	2.0	2.0	392	784	2.0	36,800	5,900	784	8.8-10.8

[1] Without any specific work, gelding and mare are concerned by these allowances. For stallion, add 0.3 UFC and 20 g MADC.

[2] Pony is considered to work 2 hours a day in a riding school (average observed in the field).

[3] Hacking: in the case of short hacking, very light work for 1 hour ride, and light work for 2 hours ride.

[4] Ponies are considered to work 1 hour daily (average observed in the field).

[5] Included daily 1 hour very light work for stallions box-stalled.

[6] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.8. Recommended nutrients allowances and intake allowances for the pony mare adult bodyweight of **400 kg**.[1]

Physiological status		Daily nutrients allowances																			Dry matter intake[2] (kg)
		UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Dry		3.2	230	21	16	11	6	8	32	20	70	350	1.4	1.4	280	560	1.4	22,800	2,800	420	6.0-8.0
Gestation																					
0-5 months		3.2	230	21	16	11	6	8	32	24	70	350	1.4	1.4	280	560	1.4	22,800	2,800	420	6.0-8.0
6th month		3.4	280	26	20	14	6	8	32	25	73	365	1.5	1.5	290	580	1.5	30,500	4,400	580	6.0-8.5
7th month		3.6	282	26	22	16	6	9	32	25	73	365	1.5	1.5	290	580	1.5	30,500	4,400	580	6.0-8.5
8th month		3.8	298	27	23	17	6	9	32	25	73	365	1.5	1.5	290	580	1.5	30,500	4,400	580	6.0-8.5
9th month		4.0	326	30	27	20	6	9	32	26	78	390	1.6	1.6	310	620	1.6	32,600	4,700	620	6.5-9.0
10th month		4.2	389	35	31	22	6	9	32	26	83	410	1.7	1.7	330	660	1.7	34,700	5,000	660	7.0-9.5
11th month		4.3	417	38	33	25	6	9	32	26	88	440	1.8	1.8	350	700	1.8	36,700	5,300	700	7.5-10.0
Lactation (kg milk/d)																					
1st month	12.0	6.7	758	61	45	39	9	10	38	62	110	550	2.2	2.2	440	880	2.2	41,800	6,600	550	9.5-12.5
2nd month	13.2	6.8	732	65	40	33	8	10	38	62	120	600	2.4	2.4	480	960	2.4	45,600	7,200	600	10.5-13.5
3rd month	12.8	6.4	691	63	39	33	8	10	38	61	120	600	2.4	2.4	480	960	2.4	45,600	7,200	600	10.5-13.5
4th month	11.6	6.0	566	59	32	27	7	9	37	53	110	550	2.2	2.2	440	880	2.2	41,800	6,600	550	9.5-12.5
5th month	8.8	5.2	424	50	28	23	7	9	37	52	93	460	1.9	1.9	370	740	1.9	35,150	5,550	460	8.0-10.5
6th month	8.0	5.1	406	47	27	22	7	9	37	51	80	400	1.6	1.6	320	640	1.6	30,400	4,800	400	7.0-9.0

[1] Bodyweight 24 h after a good foaling.

[2] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

Table 8.9. Recommended nutrients allowances and intake allowances during growth of the pony adult bodyweight of **400 kg**.

Age (months)	Average weight[1] (kg)	Growth, bodyweight gain (g/d)	Daily nutrients allowances																		Dry matter intake[2] (kg)
			UFC	MADC (g)	Lysine (g)	Ca (g)	P (g)	Mg (g)	Na (g)	Cl (g)	K (g)	Cu (g)	Zn (g)	Co (g)	Se (g)	Mn (g)	Fe (g)	I (g)	Vit. A (UI)	Vit. D (UI)	Vit. E (UI)	
Growth – husbandry																						
6-12	218	420	3.6	388	34	25	18	4	5	17	15	58	288	1.2	1.2	230	288	1.2	19,800	3,500	460	5.0-6.5
18-24	328	180	4.5	265	28	29	20	5	7	26	21	70	350	1.4	1.4	280	350	1.4	24,500	3,500	420	6.5-7.5
30-36	372	90	4.9	255	27	32	21	6	8	30	24	75	375	1.5	1.5	300	375	1.5	26,300	3,800	450	7.0-8.0

[1] Median bodyweight during the period.

[2] The smallest values are chosen for a ration high in concentrates and the largest values are to maximise forage intake.

8.2.1 Critical temperatures

8.2.1.1 Definition

Thermoneutral zone (TNZ) corresponds to the range of temperatures where body temperature of the animal and environmental temperature are balanced. The animal steadily maintains its body temperature at 38 °C without extra energy expenditure. Low critical temperature (LCT) and high critical temperature (HCT) are the temperatures at the extremes of the TNZ, under or over respectively, where the horse may have trouble regulating its body temperature without any external assistance.

8.2.1.2 Ranges

In the adult horse at maintenance, which is adapted to temperate climatic conditions, the TNZ falls within +5 °C and +25 °C (e.g. +5 °C < TNZ < +25 °C). In the adult horse adapted to cold temperatures, but fed 50% over energy requirement at maintenance, the TNZ falls within -15 °C and +10 °C (e.g. -15 °C < TNZ < +10 °C). Hence, low critical temperature ranges between -15 °C and +5 °C (e.g. -15 °C < LCT < +5 °C) and high critical temperature ranges between +10 °C and +25 °C (e.g. +10 °C < HCT < +25 °C) for horses placed under temperate and cold climatic conditions. The thermoneutral zone is quite large because the body surface of the horse is relatively low with respect to its bodyweight. These limits should be further established with more data under hot climatic conditions.

In the young horse (>6 months) adapted to cold temperatures, but well fed, the TNZ would range between -10 °C and +16 °C (e.g.-10 °C < LNT < +16 °C). However, the new-born is much less tolerant during the first nine days following birth. The low and high temperatures would fall between +20 °C (LCT) and +36 to +40 °C (HCT), respectively. The LCT might be lower if the new-born is sheltered with bedding.

The effect of lower temperatures is influenced by wind and/or rain. Consequently, the previously mentioned LCT would be altered when there are no means implemented to help the horse cope with such conditions. The effect of high temperatures elevates because the animal will increase sweating to regulate its body temperature. This physiological process costs energy. Energy requirements of horses measured by calorimetry and in feeding trials at INRA are 9% higher in summer (+ 25-30 °C) than in winter (+5 to -5 °C). High temperature combined with high relative humidity (HR> 60%) decreases the efficiency of evaporation by the skin to maintain body temperature. Therefore, a shady area or well ventilated shelter is recommended for the horse grazing summer pastures.

8.2.1.3 Factors of variation

The energy requirement of young light breed horses (2-3 years old) fed a mixed diet (60% poor quality hay supplemented with 40% of a barley-based concentrate) measured at INRA by calorimetry or feeding trials is 11% higher in summer than in winter in a temperate zone. LCT of Thoroughbred and light horse is not different. In contrast, LCT is less favourable in horse because the ratio between body surface and bodyweight is higher.

During the competition season, the LCT of a horse would be less favourable compared with a horse at rest *sensu stricto* (e.g. no competition or training) because most of the energy expenditure and the mechanism involved in its regulation are mainly oriented toward the expenditure linked to work. The difference of LCT might range within 1.5 and 2.0 °C.

In general, horse with intact winter coat is the most cold resistant and the clipped horse on maintenance is the least cold resistant. Clipping a horse raises the LCT by 4 to 5 °C.

8.2.2 Adaptation

8.2.2.1 Duration

The period of adaptation of a horse to permanent hot or cold climatic conditions ranges within 2 to 3 weeks. The duration is shorter when the magnitude of the variation between day and night is limited and repeated during subsequent days.

8.2.2.2 Energy metabolism

Energy expenditure of adult horse at maintenance in the TNZ (e.g. the reference) is 3 to 4 times higher when horse is subjected to low temperature -15 and -20 °C. The reference energy expenditure would increase linearly by +2.5%/Celsius degree below LCT.

The elevation of energy expenditure in a horse subjected to low temperatures is regulated by the extra heat which is produced during digestive and metabolic utilisation of feeds (Chapter 1). The production of extra heat is higher with forage-based diets than with mixed diets: 10 to 20%. The extra heat production elevates with the amount of feed (feeding level): for example, +39% when the feeding level of the adult is 1.3 times maintenance, as measured by indirect calorimetry at INRA.

Energy requirements of adult horses fed a mixed diet (60% poor quality hay supplemented with 40% of a barley based-concentrate) measured at INRA by calorimetry or feeding trials is 9% lower in summer than in winter in temperate zone.

8.2.2.3 Prevention

The horse can be managed outside in any season as long as simple means are implemented when the horse is out of its TNZ. The horse should be in good body condition (BCS ≥3) and also given time to adapt. Activity of the horse wintered in open paddocks is higher than in a stall or when grazing during the summer. Therefore, additional allowances should be supplied: at minimum +0.5 UFC and 20 g MADC in any climatic conditions (Chapter 6, Figure 6.11).

In the winter

Shelter should be provided for the horse that is wintered day and night outside to minimize the effect of wind and rain or snow. The horse which is stalled during the night may be blanketed to go out during the day and/or during the adaptation period for the horse expected to be wintered outside. Those two means reduce energy expenditure by 9 to 26% according to the climatic conditions.

The amount of feed and the proportion of forage in the diet should be increased as the temperature decreases. Energy allowances at maintenance should be elevated by 1.5 to 2.5% per Celsius degree below -5 and -10 °C, e.g. +0.06 UFC and +0.10 UFC per degree for the adult horse of 500 kg BW.

Example 8.1 Adult horse 500 kg BW and temperature -5 °C

Maintenance requirement (strict):	4.1 UFC (Chapter 6, Figure 6.13)
Additional requirement for moving:	+0.5 UFC
Additional requirement for climate:	+0.3 UFC (0.06 × 5 = 0.3 UFC)
Total requirements =	4.9 UFC

Proportion of forage in the ration should be 90% and amount of feeds are increased as far as energy requirements rise.

Energy allowances: 4.9 UFC

Total dry matter intake requested to meet requirements 9-10 kg DM (9 × 0.90 or 10 × 0.90 = 8.1 to 9.0 kg DM of forages)

Watering should be free choice as far as horse is fed high forage-based diet.

In the summer

Natural shade (trees) or shelter are recommended for horses as soon as the temperature is higher than 25 °C, even when the horse is grazing, because energy expenditures rise, especially if the horse is young. Horses are given shade by some breeders in the middle of the day.

For the adult exercising horse that is routinely turned out in an open-paddock, extra heat produced by the diet can be reduced with the substitution of fat on an energy basis to maintain energy density of the ration, especially for the highly exercised horse. Thus, 5% fat in the ration decreases, extra heat by 10 to 14%. Protein content of the ration should be limited for the same reason.

Sufficient water intake is of very high concern during high temperatures, and the detrimental losses of electrolytes (sodium, potassium and chlorine) from sweating. A mineral salt block should be offered free choice to horses, whether stalled or grazing, as well as free choice access to clean water.

8.3 Aged horses

Horses are living longer and longer. The number of horses which are devoted to hacking has been increasing for many years: for example in France 80% of riders are amateurs; 1.5 million are regular riders, but at least 2.0 million others are occasional riders. As a result, nearly 80% of equine population in France (e.g. 1 million) are expected to get old. In contrast to racing and sport horses, they are used less intensively. Nowadays, there are ethical reasons for trying to preserve aged horses as long as possible.

8.3.1 Definition

At what age could a horse be considered an aged horse? Chronologically compared to the human, the horse that is 20 years old corresponds to the human who is 60 years old, e.g. a ratio which ranges 1:3 according to age. This ratio is valid in the horse from 3 years of age and up. However, this is really not the only factor affecting aging. Rate of aging relies on the type of use of the horse and there is huge individual variation.

Indeed, horses do get old since external aging signs appear. Physiological and metabolic functions decrease with age, but not under the influence of any pathology which would affect the horse, even though there are pathologies that arise as a consequence of aging. This last situation applies to the domain of veterinary medicine for geriatrics.

8.3.2 Status

Different signs appear with aging in the horse: physical aspect – behaviour – tissue and organ functions.

Physical signs of aging are grey hairs appearing around eyes, nostrils and sometimes even over the body, the horse may get sway-backed, withers and hips become more or less thin and bony, and the backbone can become pronounced. Feeding behaviour of the aged horse changes insidiously: preferences, appetite, ingestion rate during main meals, irregular and limited watering which can lead sometimes to some dehydration. The horse may be notably less and less stimulated by the environment (other horses, man, etc.). At this time, the horse should be observed by staff and owners and not left on its own. With aging, body condition decreases: fat content declines and body condition score falls down to around a 2.5, muscular mass decreases as well and osteoporosis signs arise more or less quickly. Infectious disorders can be produced in accidental lesions.

Efficiency of digestion may be reduced (-5 points for DM digestibility has been measured). Pasty or soft faeces that are close to diarrohea can sometimes occur, and in all cases they can become very irregular in their aspects, frequency and quantities. The adult horse produces 15 to 30 kg of fresh manure daily with an average of 20% DM. However, digestive stasis and even obstruction (e.g. slowing down or break down of digesta transit) may occur.

Nutrients requirements are sometimes not met because supplies of nutrients from feeds are limited by poor digestion and absorption.

Finally, clearance of by-products of digestion and metabolism of nutrients may be impaired due to a slowdown in activity of the liver and kidneys. From this the urine can become irregular, more or less dark and foul-smelling.

All these signals highlight the inescapable decline of secretions and hormonal activities (sexual, somatotropin, insulin, etc.) which regulate these functions and organs, metabolisms of tissue and immune system.

8.3.3 Nutrients requirements

Energy requirements at maintenance decrease with age in old horse as in man (-10 to -20%) because spontaneous physical activity decline and correspondingly muscular mass as well. Protein requirement at maintenance diminishes in the aged horse, as in humans (-20 to -35%), due to an imbalance between the catabolism and anabolism of proteins, and a reduction in the efficiency rate of feed protein utilisation that cause loss of muscle mass. Mineral requirements could increase in response of decrease of their digestibility by -4 to -11 points for phosphorus according digestion trial carried out in equines.

8.3.4 Feeding

The objective of feeding the aged horse is to nourish for optimal physiological and metabolic function in the context of diminishing or limiting the effects of aging. Unfortunately, experimental data on the aged horse is scarce.

In addition to proper feeding, the horse should be managed in a stimulating environment to keep up spontaneous physical activity (paddock, opened pen, pasture) and given short but regular training exercise to maintain muscle mass and skeletal strength. In this last case, exercise promotes production of bone mass. Teeth should be controlled and general condition should be routinely evaluated by a veterinarian.

The ration should be able to maintain a steady optimum bodyweight and body condition (BCS >2.5, ideally 3.0) (Chapter 1 and 2) because losses are difficult to be restored. The diet should be composed of forage and concentrate, even if exercise is limited. The crude fibre content of a ration should average 20% DM at a minimum. Diet composition and characteristics are dependent on the history of the horse, ability to maintain body condition and physical activity. Tables of recommended allowances in Chapter 6 corresponding to idle and/or very light exercise can be used in this circumstance. Recommendations given in Chapter 2 about management of body condition of horse may be used as well but adapted to the aged horse.

Different choices of types of feeds can be used to stimulate appetite and digestion. Wrapped bale silage with a high dry matter content (60-70%) may be preferred to hay (Chapter 9 and 11) because the palatability is better and it is dustless. Forages harvested at early heading stage are richer in simple carbohydrates (sugars) and proteins, and subsequently more digestible (Chapter 12 and 16). If chewing is difficult for the horse, hay may be chopped. For the concentrate, the proportion of cereals grains should be limited to prevent digestive disorders and metabolic intolerance towards complex carbohydrates (starch), and thus relying on low glycemic regulation by pancreatic insulin. Fat may be substituted for a portion of the cereal grains as needed for energy. In addition, wheat bran or linseed meal may be interesting additions as they are rich in hemicelluloses or mucilage, respectively, which promote intestinal transit. When the horse has trouble with the teeth, concentrates should be fed as either soft pellets or extruded nuggets rather than normal hard pellets. The appetite can be stimulated with the addition of carrots, beets or apples, but only in limited amounts because they are slightly laxative.

Protein content of the ration should range between 10-12% CP/DM (Chapter 2 and 6). Good quality protein should be fed, such as soybean meal or alfalfa meal; or even protein from milk by-products, as they are highly digestible and very often rich in lysine and threonine (Chapter 9 and 16). Feeds rich in essential fatty acids, namely vegetable oils (soybean, flax and canola) or fish oils (autolysats or hydrolysats) with antioxidants to prevent rancidity are a good addition.

Sometimes dietetic feeds (Chapter 9) may be used for short periods when the horse is coping with digestive or metabolic disorders, once a disturbed nutritional status has been diagnosed by the horse's regular veterinarian.

The horse should graze pastures when the grass is early to full heading (Chapter 10 and 12) and in sufficient quantity (Chapter 10). Rotational grazing is recommended to make efficient use of available forage and to control parasites (Chapter 1, 2 and 10). Shelter should be available during hot periods because the heat increases energy expenditure (Chapter 1). There should be a permanent good quality water supply (Chapter 2) and a mineral supplement should be provided in the form of free choice minerals salt blocks (Chapter 2 and 13).

8.4 Donkey

8.4.1 Introduction

The donkey, *Equus asinus*, belongs to *Equidea* family. As a matter of fact, the donkey falls into the same genus as horse (*Equus*), but is a different species (*asinus*). In the temperate zone, the donkey is not nearly as important as it was in the past, but thankfully many breeds have been preserved because of specialised breeding programs. In the last decade, the donkey has been receiving more interest as a companion animal and also in the tourist industry as pack-animals for trekking. There is still a demand for working donkeys in countries in the hot zones. Donkeys are usually kept on pastures and wintered in paddocks where they are fed with preserved forages and some supplements. In some countries, such as Italy, herds of jennies are managed for milk production, which is used for human new-borns that have allergies to conventional baby formulas. Herds of mares are mechanically milked on specialised farms on range lands in the south of the country. As a result, knowledge of milk yield and composition in the jenny has greatly improved. Jennies are fed mainly hay and cereal grains that are harvested on the large size farm, with some supplements.

In hot zones (dry or humid), donkeys are mostly used for work (agriculture and transport) mainly in developing countries that are highly involved in a rural economy. Referring to FAO, 56 million donkeys (and mules) are working worldwide: in Asia (23 million), in Africa (17 million), in South America (9 million) and other countries (9 million). In Africa, donkeys are raised and used in intermediate areas, half-arid and sub-tropical: 400 to 800 m and 800-1,200 mm rain, respectively, according to CIRAD‘s observations. In these agricultural areas, donkeys are harnessed for soil preparation and harrowing food crops. Donkeys are preferred to oxen because their power is 116 watts/100kg BW compared to 80 watts/100 kg BW; and their maintenance is easier.

8.4.2 Nutritional status

A donkey's intake, expressed per kg BW, is close to or even higher than that of a pony when these animals are both fed free choice average or poor quality forages in the long or pelleted form, and supplemented or not with only energy or both energy and protein. The donkey seems more adapted than the pony to maintain intake when the quality of the forage is declining or increasing (Table 8.10).

Generally, digestibility of forages is higher in the donkey than in the pony, because the donkey is better at digesting cell walls. However, these differences are attenuated when forages, namely straw, are supplemented with just energy or combined with protein (Table 8.11).

Table 8.10. Daily dry matter intake (g/kg $BW^{0.75}$) in the donkey and pony (adapted from Suhartanto and Tisserand, 1996; Tisserand *et al.*, 1991).

Animal species	Straw						Hay (cocksfoot + alfalfa)	
	Alone	Molassed	Pelleted	Supplemented			Long	Pelleted
				Cereals grains	Cereals grains + soybean meals	Cereals grains + urea		
Donkey	58-62	57	50	59	64	61	88	59
Pony	41-53	53	48	37	41	42	101	57

Table 8.11. Digestibility of forages fed alone or supplemented to donkey or ponies (adapted from Tisserand *et al.*, 1991; Suhartanto *et al.*, 1992).

Animal species	Straw						Hay	
	Alone			Supplemented			Long	Pelleted
	Long	Molassed	Pelleted	Cereals grains	Cereal grains + soybean meals	Cereals grains + urea		
	Organic matter							
Donkey	34-40	52	48	52	46	54	55	57
Pony	35-39	46	42	53	50	59	52	52
	Cell walls: crude fibre or neutral detergent fibre							
Donkey	(38)-41	(46)	47	38	31	41	42	48
Pony	(38)-40	(41)	39	34	29	41	41	47
	Crude protein							
Donkey	-	54	-	50	65	67	69	-
Pony	-	44	-	49	64	68	65	-

Discrepancies in digestibility may also be explained by the donkey's greater ability to select for the most digestible part of poor quality forages, particularly those fed only free choice, and by donkey's capacity to increase retention time of feeds in digestive tract.

In the donkey, as in the pony, digestibility of poor quality forages (straw) is of course lower than that of good quality forages (hay) (Table 8.11). Organic matter digestibility of poor quality forages is improved in the donkey when forages are supplemented with cereal grains or with protein sources, because digestibility of protein is mainly better in the donkey than in the pony. However, this improvement is not as notable in the donkey as it is in the pony.

Cell wall digestibility of forages is higher in the donkey than in the pony (Table 8.11) because cellulolytic activities of bacteria involved in digestion were on average 17% higher when both animal species are fed with forage mixtures of cocksfoot and alfalfa or wheat straw. Volatile fatty acid production in large intestine, the major source of energy, is 28 to 40% higher in the donkey than in the pony fed with wheat straw offered free choice alone or supplemented with cereal grains combined or not with protein sources (soybean meal or urea).

Protein digestibility seems to be similar in the donkey and the pony for a wheat straw-based diet supplemented or hay-based diet. In contrast, digestibility is higher in the donkey fed with poor quality forages (Table 8.11) because the donkey is capable of recycling 75% of endogenous urea whereas in the pony only 50% is when protein allowances are too low.

8.4.3 Milk yield and composition

Milk yield of the jenny has been evaluated thanks to the many studies carried out in Italy in animals that are mechanically milked to get milk for medical reasons. Daily milk yield averages 0.8 to 2.0 l during lactation that lasts 200 to 300 days, which equates to about 0.5 to 1.3 l/100 kg BW in Italian breeds (Martina Franca, Ragusano, Romagnolo and Griogio Sciciliano). Milk yield is related to the date of foaling and the date of turn out on grass. Milk yield declines in the jenny with the stage of lactation, just as seen in the mare.

Dry matter, lipid, protein and mineral content of milk is low but lactose content is very high (Table 8.12). Fat content is rich in short and medium chain fatty acids and in polyunsaturated C18-2n-6 and C18-n-3 fatty acids.

Crude protein content is rich in caseins mainly, and to a lesser extent in proteins of lactoserum and non-protein nitrogen. Fat and protein content decline during lactation, whereas lactose content rises to a plateau while energy content decreases.

8.4.4 Metabolism and requirements

8.4.4.1 Energy expenditure

Energy expenditure is evaluated from oxygen consumption at rest or from practical observations carried out in feeding trials and expressed with respect to metabolic bodyweight, and is 20-25% lower than in the horse. Thus, the maintenance requirement of the donkey cannot be extrapolated

Table 8.12. Comparison between milk of the jenny and other mammalian species (adapted from Doreau and Martin-Rosset, 2002; Doreau *et al.*, 2002; Martuzzi and Doreau, 2006; Polidori, 1994; Salimei and Chiofalo, 2006).

	Jenny	Mare	Woman	Cow
Dry matter	80-180	100-120	110-122	120-130
Fat	3-6	10-20	35-40	35-42
Protein	14-19	15-28	9-17	31-38
Lactose	65-69	55-65	65-70	45-50
Minerals	3-4	3-5	18-22	7-8

from that of the horse. Energy requirement would likely be lower in the donkey than in the pony; 0.0320-0.0300 kcal NE/kg $BW^{0.75}$. In the absence of more accurate data, maintenance requirement is considered to be similar to that of the pony: 0.0333 kcal NE/kg $BW^{0.75}$.

Energy expenditure in the working donkey expressed as a value relative to maintenance varies as in the horse but is lower when the donkey is standing up with a load (Table 8.13). Energy expenditure with a light cart or a harrow walking a 10 km distance expressed as a relative value to maintenance ranges between 1.57 to 1.91 and 1.56 to 1.85 in the donkey and the pony respectively. The energy requirement evaluated per metabolic weight in the working pony can be used in the working donkey as well.

8.4.4.2 Protein expenditure

Protein expenditure has not been measured yet, but it is logical to believe that it is, as in the horse and pony, linked to energy expenditure at rest and for work. However, protein expenditure is likely lower than in the horse and probably in the pony since the digestive capacity of feed protein utilisation or endogenous urea recycling is more efficient. Therefore, protein requirements designed for pony can be used in donkey as well.

Table 8.13. Energy expenditure in the donkey and the horse (adapted from Guerouali *et al.*, 2003).

Animal species	Rest kcal/kg $BW^{0,75}$	Multiple of maintenance		
		Rest + load	Walk	Walk + load
Donkey	12.6	×1.2	×1.8[a]	2.1
Horse	15.2	×1.4	×1.7	2.0

[a] 1.7; from Dijkman (1992).

8.4.4.3 Water requirement

Water requirement in the donkey ranges within 35 to 75 g/kg BW according to activity, climatic conditions and type of diet. The donkey can handle water deprivation well since it can withstand a 30% loss of bodyweight. It is also capable of prompt rehydration when water is available again free choice. The donkey can maintain 80-82% of the forage intake during the 36 to 48 hours following water deprivation, whereas intake is only 70-75% in the pony.

8.4.5 Feeding recommendations

8.4.5.1 Recommended nutrients allowances

There are very few recommendations evaluated in donkey using nutrients expenditure that are validated enough with long term feeding trials as in horse (Chapter 1 to 5), except for work (see the reviews of Pearson, 2005; Pearson and Vall, 1998; Ram *et al.*, 2004).

8.4.5.2 Feeding and watering

Under temperate climate

Under these conditions, the donkey may be fed like the pony, but with at least 80% of the forage in the diet harvested at late heading or even early flowering, and taking into consideration the donkey's lighter bodyweight: 100 to 200 kg BW.

Under hot climate

Donkeys are fed forages with high cell wall content harvested from locally grown forages and pasture grasses according to dry or wet season, from cereal grain by-products (straw of millet, rice, sorghum, stovers and husks of maize), and cotton and by-products of the food industry (nut hulls, cotton or nut meals, brewers yeasts and cereals bran).

Few experimental data are available to give some guidelines on the amount of forage and concentrate to be fed (Table 8.14 and 8.15) and water offered (Table 8.16). The proportion of concentrates increases as long as the duration of work rises. There is no substitution of concentrate for forage in the donkey, at least with poor quality forage-based diets supplemented with 20 to 35% concentrates. Therefore, the amount of forage fed at rest or very light work should be maintained at work even when the amount of concentrate is increased.

Water intake should be evaluated with respect to normal bodyweight (e.g. estimated during long resting period) and climatic conditions: temperature and humidity integrated in a single index temperature-humidity (ITH).

Table 8.14. Rations for the donkey at rest and lactating jenny (kg DM/100 kg BW) (adapted from Pearson, 2005).

	Forage[1]	Concentrate	Total
Maintenance	2.2-2.5	0.0-0.25	2.5
Lactation (0-3 months)	0.6-0.8	1.2-1.4	2.0

[1] According to quality.

Table 8.15. Examples of rations tested in a sub-Saharian tropical zone (Cameroon) (kg DM/100 kg BW) (adapted from Vall *et al.*, 2003a).

Duration of work	Pulling force							
	Rest		Relative to bodyweight					
			10%		14%		18%	
	F[1]	C[2]	F	C	F	C	F	C
0 h	1.8	0.34	-	-	-	-	-	-
1 h			1.9	0.52	1.9	0.59	1.9	0.64
2 h	-	-	2.0	0.69	2.0	0.84	1.9	0.92
3 h	-	-	2.1	0.87	2.0	1.08	-	-
4 h	-	-	2.1	1.04	-	-	-	-

[1] Maize stovers.
[2] Concentrate: 32% cotton seeds + 32% wheat bran + 32% brewers yeasts + 4% mineral and vitamin supplement.

Table 8.16. Water intakes of the working donkey corresponding to rations tested in a sub-Saharian tropical zone (Cameroon) (l/100 kg BW) (adapted from Vall *et al.*, 2003a).

Duration of work	Pulling force			
	Rest	Relative to bodyweight		
		10%	14%	18%
0 h	7.7-10.0	-	-	-
2 h	-	10.4-11.0	8.3-11.1	10.6-11.2
3 h	-	11.9-14.9	11.8-14.6	-

Water intake with work ranges within 1.1 to 1.5 times resting intake (Table 8.16). Individual variability averages 5% but day to day variability is higher at 13% on average. Water intake is 20-25% higher in a hot season than in a cold season. Water intake (WI) of the donkey can be predicted from work duration (D_w), climatic index (ITH), and work intensity (I_w) using the equation proposed by Vall *et al.* (2003a):

$$WI\ (l/d) = 0.79\ D_w + 0.51\ ITH + 0.09\ I_w - 32.34 \qquad R^2=0.87$$

For rapid estimation, the following water intake coefficients may be used: 0.8 l per hour of work and 0.5 l per point ITH.

8.4.5.3 Bodyweight and body condition score prediction

Rations should be formulated according to bodyweight and body condition score, as in the horse. A method of predicting bodyweight which is specific to the donkey has been designed using a large population of donkeys from Morocco by Pearson and Ouassat (1996). Two models are proposed according to age:

Adult (74-353 kg ≥3 years)

$$BW\ (\pm 20) = \frac{TP^{2.12} \times L^{0.688}}{3{,}801} \qquad n=500 \qquad R^2 = 0.84$$

BW: bodyweight (kg); TP: thoracic perimeter or girth (cm) (for measurement see Chapter 2, Figure 2.1); L: length (cm) measurement between the bony point of the shoulder and the bony point of the buttock.

Young (52-158 kg <3 years)

$$BW\ (\pm 11) = \frac{OP^{1.40} \times L^{1.09}}{1000} \qquad n=16 \qquad R^2=0.87$$

BW: bodyweight; OP: umbilical perimeter (cm), measurement of trunk perimeter at the place of umbilici; L: length (cm), measurement as in adult.

A visual appraisal method of body condition specific to the donkey has been designed by CIRAD using a large population of five types of donkeys in Cameroon. The method has been validated with feeding trails and in the field during the annual cycle of donkey activities. It is described in Figure 8.1.

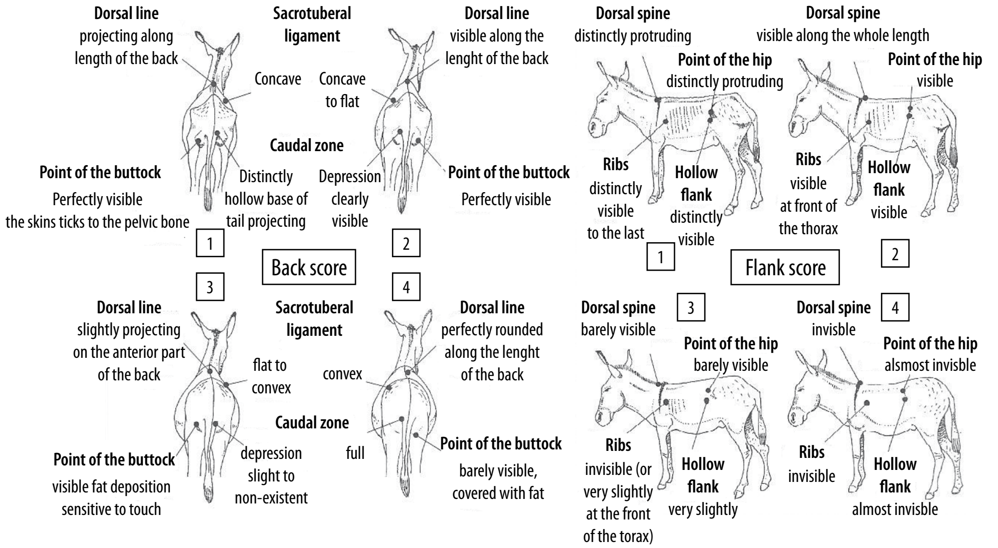

Figure 8.1. Diagram of the method of visual appraisal method of body condition score (adapted from Vall *et al.*, 2003b).

References

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Chapter 9. Feeds, additives and contaminants

William Martin-Rosset, Catherine Trillaud-Geyl and Yves Bonnaire

The nutritive value and the conditions of utilisation of feeds need to be well understood to build balanced rations that are consumed well by the horse. The feedstuffs available to feed to the horse are numerous and diverse (see tables, Chapter 16). Their nutritive value (energy, protein, mineral, etc.) depends on their chemical composition (Chapter 12). This varies with the nature of the feeds (species, parts of the plant, etc.), vegetative state, conditions of harvesting and conservation (Chapter 11) and eventually the processing (grinding, cooking, etc.).

The animal feed industry uses or proposes to use food additives to improve the characteristics of the feeds, health and performance of animals that can be identified and also make their interest known.

The feeds from crop production, e.g. raw materials, as well as the commercial concentrate feeds produced from these raw materials can naturally contain contaminants from certain plants that have doping properties under the regulations of equine competitions. It is important to know these plants to remove them from horse feeds, and for feed manufacturers to implement analytical controls for their detection. There are:

- Roughages which include the stems, leaves, flowers and roots of forage plants. They have energy and (or) protein contents that range from 0.30 to 0.80 UFC and 0 to 170 g MADC per kg dry matter.
- Simple concentrated feedstuffs come from grains or seeds of plants such as cereals (barley, oats, etc.), the legumes (peas, faba bean, soya, etc.) or by-products of grain processing or oil seed meals from the oil industry. The grains or seeds have a high energy and/or protein content: from 0.60 to 1.33 UFC and from 61 to 452 g MADC per kg DM, plus they are high in starch (cereal grains) or in fat and protein (linseeds, sunflower seeds, soybean seeds, etc.).
- The simple concentrated feedstuffs are combined by the feed industry in variable proportions to formulate compound feeds, where the energy value can vary from 0.8 to 1.1 UFC and 90 to 180 g MADC.

9.1 Roughages

9.1.1 Forages

These are forages made from the above ground parts of plants (stems, leaves, and heads) or immature and mature cereal grains with or without the seeds, cultivated or native plants of different stages of development.

Based on the amount of dry matter and method of conservation there are:

- green forages: 12 to 30% dry matter;
- conserved forages: silage/haylage (30 to 60% dry matter) and hay or dehydrated forages (84 to 92% dry matter).

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9.1.1.1 Green forages

Green forages can be almost the entire diet of the horse on pasture. Ryegrass(*Lolium perenne*), meadow fescue (*Festuca pratensis*) and red fescue (*Festuca rubra*) are the forage species generally preferred by horses; to a lesser extent bluegrass(*Poa pratense*), cocksfoot or orchardgrass (*Dactylis glomerata*), bentgrass (*Agrostide communis*), timothy (*Phleum pratense*) and white clover (*Trifolium repens*); woolly houlque (*Holcus lanatus*) and bromegrass (*Bromus inermis*) are the least preferred. Grass-clover mixtures are always preferred over the pure species.

The stages of development of forages are well documented in technical handbooks. They contribute to the prediction of the nutritive value (Chapter 16). As green forage matures, the proportion of leaf to stem changes in favour of more stems and seedheads (grasses) or flowering parts (legumes) particularly during the first vegetative cycle. These changes are accompanied by a decrease in the water content of the plant (from 85 to 75% reduction) and an important reduction of nutritive value of the forage (Figure 9.1).

The nutritive value of forage is at its maximum when it is grazed during the first cycle (or during the first grazing in the spring). The nutritive value of regrowths is basically dependent on age (number of days since the previous grazing) and which cycle (order of grazing on the same plot) (Table 9.1).

However, for a given cycle, the energy value of grazed forages depends more on the species of plant than on the stage or age of growth, particularly in the case of regrowth (Table 9.2).

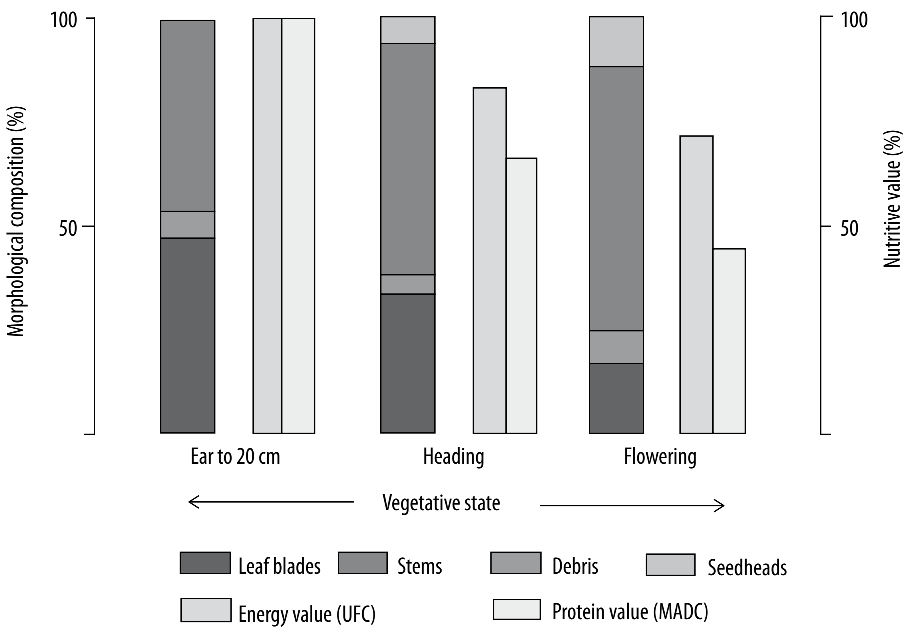

Figure 9.1. Morphological composition and nutritive value changes during maturation in green forage (example Italian ryegrass).

Table 9.1. Variation in nutritive value of native grassland pasture (Normandy, France) through the different vegetative cycles (per kg DM).

	UFC	g MADC
1st cycle – very early stage	0.76	107
2nd cycle – leafy, 5 weeks	0.72	146
2nd cycle – leafy, 7 weeks	0.69	95
3rd cycle – 6 weeks	0.70	134

Table 9.2. Nutritive value: comparison of three grass species (per kg DM).

	UFC	g MADC
1st cycle, grazing stage at 10 cm		
Cocksfoot	0.73	138
Tall fescue	0.65	101
English ryegrass	0.79	92
2nd cycle, leafy, 5 weeks		
Cocksfoot	0.62	106
Tall fescue	0.64	98
English ryegrass	0.75	112

Nitrogen fertilisation increases the crude protein content of green forages, particularly in the early vegetative stage, but not necessarily the actual protein value of the forage. It can sometimes increase the proportion of soluble nitrogen within the total nitrogen content. Soluble nitrogen is not well utilised by the horse during digestion (Chapter 1 and 12). However, it is necessary to improve the growth of the plant, depending on the quantity of grass available and the number of times grazed during the season.

As a result, pastures should be grazed in the spring when the grass attains a maximum height of 20 cm. The most opportune time for regrazing pastures can be determined by knowing the age of the regrowth and measurement of the height. The proper height for regrazing will be obtained at 4 to 5 weeks for the 2nd cycle and 5 to 7 for the 3rd cycle. The height of the plant, indicative of the quantity of plant produced and the quality (the proportion of stem) is very difficult to assess (Chapter 10).

9.1.1.2 Conserved forages

The different methods of harvesting and conservation of forages are the reason for the variability in losses relative to the freshly harvested plant (Chapter 11). Also, the losses are selective (sugars and crude protein of the cell contents) and are one of the reason for differences in the feeding value of the forage. The techniques, which should be utilised, aim to minimize the losses to the conserved forage and to maintain their nutritional characteristics close to those of the fresh plant.

Hay

Hays are harvested after prolonged sun drying (raking) or cold or hot ventilation under cover. The nutritive value of hay is always inferior to that of the corresponding green forage: the difference is even greater when the conditions of mowing, harvesting and storage are unfavourable (Chapter 11 and 12).

Grasses should be harvested in the first cutting (or hay) in the heading stage: 50% of the plants have seedheads. For legumes, wait until the budding stage (50% of plants flowering). The second cutting (or regrowth) can be harvested after 5 to 7 weeks of regrowth in both cases.

Grass hays are mostly from forages of native grassland pastures. At the same growth stage and the same amount of nitrogen fertiliser, the harvested forages in the low lands have a protein value (40 to 100 g MADC/kg DM) that is less (on average 10%) than hay grown in the mountains, but the energy value is at least equal if not better.

Legume hays (alfalfa in particular) are interesting in comparison to grass hays harvested under the same conditions. They have higher crude protein content (+20 to 25% on average) and calcium (+60% on average), but a lower energy value (-10% on average) than grasses harvested under the same conditions. First cutting alfalfa is rarely pure, unless the fields are irrigated, because grasses have faster growth in the early season.

'De Crau' hay merits a special mention because it is prized by breeders and trainers for horses, notably among racing stables. De Crau hay is produced on irrigated pastures on the Bouches-du-Rhône county (south east of France: Mediterranean) and is composed according to the cutting (1 through 3), of 30 to 50% grasses, 25 to 35% legumes and 25 to 35% diverse species. Crau hay has some typical botanical characteristics. Its energy and protein values approach those of very good meadow hays harvested under the same conditions in other regions. However, it has an elevated mineral content, calcium in particular, due to the high proportion of legumes and herbs. The quality of de Crau hay is a result of the favourable growing and harvesting conditions in the region.

Direct assessment

Natural meadow (native grassland) hays are composed of multiple species of plants; hays from temporary pastures are one grass type, in general, or one grass and one legume type; hays from cultivated pastures are only one species of legume.

To determine the vegetative stage of the plant for harvesting look for the inflorescents (seedheads) and observe their appearance:
- none or few inflorescents: hay cut very early or in regrowth;
- small inflorescents, few in number and well formed: hay cut at in early heading;
- multiple inflorescents, large and open: hay cut in full heading;
- inflorescents destroyed: hay cut too late (mature).

The stems should be relatively fine, the leaf blades abundant and well developed. Also, the highest is the proportion of leaves in total mass of the hay, the richest are the leaves in digestible nutrients: non-structural carbohydrates, proteins and minerals (Chapter 12).

Hay harvested under good conditions and stored appropriately should be green; it should have a fresh and agreeable smell, very little dust and free of foreign objects (branches, dirt, rocks). Yellow, odourless hay is indicative of hay harvested in bad weather or very old hay. Beware of mouldy hay with bleached patches and a musty smell: this is indicative of hay baled with too much moisture that has gone through heating and can provoke digestive troubles (Chapter 11). Direct assessment can enable determination of the nutritive value of forages (Tables Chapter 16).

Chemical analysis

Chemical analysis completes the direct assessment and can more accurately predict the nutritive value of forage: particularly the content of UFC, MADC, calcium and phosphorus (Chapter 12 and 16). It is essential for establishing a precise ration and can also be a rational basis for the purchases of forages: a list of principle analytical laboratories in France is available from the BIPEA: Bureau Inter professionel pour les Etudes (Interprofessional office for analytical studies: IOAS, Gennevilliers, France, www.bipea.org).

Silage

Green forages can be harvested and stored immediately in silos where it undergoes controlled fermentation (Chapter 11). Direct cut silages will have low dry matter content, equal to fresh forage: 16 to 20% depending on the climatic conditions. However, cut forage can be left in the field to partially sun-dry to get to 20 to 25% dry matter (slightly wilted silage: pre-wilted silage) or 30 to 35% dry matter (wilted silage). Energy values vary from 0. 50 to 0.64 UFC/kg DM and protein values of 45 to 95 g MADC/kg DM. The forages can be dried to 50-60% dry matter (half tedding) then packaged into large round bales of 250 to 300 kg wrapped in plastic. This is where the term wrapped round bales comes from (e.g. WRB or wrapped silage). Their energy value and protein are higher: 0.53 to 0. 70 UFC/kg DM and 50 to 110 g MADC/kg DM. Some producers package their silage in 60 kg bales for easier handling in riding schools stables and so it can be consumed quicker. Wrapped round bales should be consumed quickly within a week of opening, especially if the temperature is above 15 °C. In the Nordic countries where silage is commonly used for horses, it is packaged in 20-30 kg bags and is called 'big bales'. Some producers in France have opted for packaging silage in smaller trays of a few kilos. In principle, all the fresh forages can be ensiled, but, for the horse, legume silages (alfalfa, clover), which are poorly consumed and provoke abnormal fermentation in the large intestine, especially when consumed in large quantities, should be avoided. On the other hand, the entire corn plant is relatively easy to ensile and has good nutritive value for the horse (0.80 to 0.87 UFC and 29 to 33 g MADC per kg DM).

The necessary conditions to make good quality silage for the horse are already well-known (Chapter 11). Referring to numerous long term feeding trials experiments carried out at INRA with different types of horses (for example see Chapter 5, Section 5.4.2.2) the silage should have a dry matter content of 30% minimum both for grasses (ryegrass, fescue, meadow grasses) as well as whole corn plant, which excludes the use of direct cut silages, even if it has preservatives, from use in feeding horses because dry matter is far too low and there is not yet confident information about the use of preservatives in horses.

The horse is less tolerant than ruminants of poor quality silage. The conservation quality should be determined by laboratory analysis, when the silo is first opened (Chapter 11, Table 11.1). In practice, good silage should have a frank pale green colour, devoid of any blackish rotting or whitish coloration or light red mouldy patches.

Silage can be fed to animals after a minimum of 1 month fermentation in the silo. However, it is advisable to progressively adapt the animal to the silage (over 2 to 3 weeks) and supplement the forage with energy, protein and minerals with a concentrate feed made to balance the ration (Chapter 2 and 13).

Dehydrated forages

Given the current cost of energy, only dehydrated legumes (alfalfa) or conserved whole corn plant are of interest in the case of the horse. However, the nutritive value of dehydrated forages is usually inferior to green forages in the field. This reduction could be significant, especially in the case of protein, if the drying process is not done correctly (Chapter 11). Dehydrated alfalfa can be fed directly as a complement to a ration, or incorporated into a compound concentrate.

9.1.2 Roots, tubers and their by-products

These feedstuffs are palatable and refreshing. They can replace grass for the work horse that has little access. They have a high energy value, 0.80 to 1.10 UFC/kg DM, but are poor in crude protein (30 to 80 g MADC/kg DM) and are low in mineral content.

Carrots and fodder or sugar beets (1.10 to 1.13 UFC and 44 to 52 g MADC/kg DM) can be fed to horses in limited quantities: respectively 1.2 to 2.0 kg, 3.0 to 4.0 kg and 1.5 to 2.0 kg as fed per 100 kg bodyweight per day. However, raw potatoes are laxative: it is preferable to cook them before feeding; they can be fed at 1.0 to 2.0 kg of cooked potatoes per 100 kg bodyweight per day. Jerusalem artichokes and bananas can also be used. In all cases, these feedstuffs should be cut up to avoid obstruction in the oesophagus in horses that bolt their feed.

Sugar beet pulp (0.85 UFC and 32 g MADC/kg DM) is now readily available because of significant development of the sugar industry. They can be consumed fresh at 4.0 to 5.0 kg of fresh product per 100 kg bodyweight per day, provided they are of good quality. Ensiled beet pulp is not accepted well by the horse and can provoke digestive problems. On the other hand, dehydrated pulp is relatively easy to use. They are consumed very well in the form of shreds, but only moderately in the pelleted form because the pellets are so hard (unless they are broken up). Sometimes they can cause indigestion when fed alone and consumed in large quantity because of their strong absorptive capacity (water) and when there is not free choice access for drinking (automatic waterers). That is why they are commonly incorporated into compound feeds.

Beet or cane molasses (1.19 UFC and 26 to 11 g MADC/kg DM) are by-products of the sugar industry. They contain a high percentage of rapidly available sugars (65% DM). However they are high in potassium and nitrates that can make them laxative and diuretic if fed in large amounts (more than 10% of the ration which is 0.2 to 0.3 kg of product per 100 kg bodyweight per day). Beet and cane molasses are similar in composition, except the amount of potassium is higher in cane. They are mostly used in making compound feeds, at 5 to 10% to improve palatability and consistency.

9.1.3 Crop by-products

Wheat and barley straw are more commonly used than oat or rye straw. Also straw is harvested during seed production of grasses (ryegrass, etc.) and legumes (pea). Straw has low energy value (0.32 to 0.39 UFC/kg DM) because it is composed almost exclusively of mature stems. Oat and barley straw have energy values more than 10 to 15% higher than wheat or rye. Pea straw has an energy value comparable to oats. The MADC content is zero for cereals and limited for forage grasses (20 to 40 g/kg DM), but higher in the legume straws (pea) or seed forages (20 to 40 g/kg DM). Straws are almost totally devoid of major minerals (calcium and phosphorus) trace elements and vitamin A, the exception is pea straw which has some calcium and moderate amounts of phosphorus. The nutrient needs of the animal should be in most cases covered by complementary compound feeds.

Horses consume less straw than hay (1.0 to 1.8 kg compared to 1.5 to 3.0 kg of DM/100 kg bodyweight) because straw remains longer in the large intestine due to low digestibility. This is why colic or intestinal impaction sometimes occurs with consuming too much straw (Chapter 2). Restricting intake usually is sufficient to prevent these problems. However, straw that is collected soon after the grain is harvested is more appetising than straw that is left a long time in the field being exposed to sun or rain. Finally, oat straw is generally better consumed than barley straw or certainly wheat straw.

Straw treated with sodium hydroxide or ammonia under good conditions (INRA, 1987) are consumed well by horses. They are usable 1 to 3 months after treatment, depending on whether it is summer or autumn. These treatments improve the energy value of straw by 15 to 25% depending on the plant species (Chapter 16), the initial quality of the hay and the treatment conditions. Treatment with ammonia has the advantage of not affecting the mineral composition of native straws and doubling or tripling the total protein. These treatments cannot exclude the necessity of some complementary source of energy, protein (only a part of the protein after treatment can be utilised by the horse (Chapter 12)) and also minerals and vitamins. The treatment also has the advantage of reducing the risk of colic.

Corn stalks and husks have a higher energy value than straws (0.50 UFC/kg DM) and close to average quality grass hays. They should be fed soon after harvest because the nutritional value progressively decreases during the drying time in the field, from loss of leaves.

Beet leaves and tops have an energy value of interest (0.60 to 0.70 UFC/kg DM) and are quite rich in total protein (130 to 150 g of MAT/kg DM). They should always be fed in limited quantity (1.0 to 2.0 kg of fresh product per 100 kg of bodyweight) because they have a strong laxative effect from the very high potassium levels. Beet leaves also contain a lot of oxalic acid that transforms into oxalate crystals after absorption in the intestinal tract and causes urinary problems, especially when consumed in excess amounts.

9.2 Concentrate feeds

9.2.1 Feed materials (simple feeds or raw materials or ingredients)

These are the feed materials that are, after different types of processing, fed alone or incorporated into commercial compound feeds.

9.2.1.1 Grains (cereal grains)

Grains are rich in readily available energy, stored in the form of starch (40 to 75% DM) but only have a protein value of 66 to 116 g MADC/kg DM. They are poor in lysine content as well. Their mineral content is very out of balance; calcium content is low. However, they are high in phosphorus which is mostly in a poorly assimilable form: phytic acid. Calcium and phosphorus ratio varies in the grains between 0.10 and 0.25, which are well below the optimal ratio of 1.5 (Chapter 2). Therefore, we must pay particular attention to the mineral balance in high grain diets (the same goes for by-products).

Oats are the cereal grain that are used the most in feeding working horses for little other reason than tradition and habit. Its energy value (0.99 UFC/kg DM) is less than other cereal grains (15 to 30% equal weight; Figure 9.2). But the crude protein content is the highest (78 g MADC/kg DM) and has the best amino acid balance. The difference between white, black or grey oats is not significant in nutritive value. However, oats should be heavy, that is to say, have a high density to be better quality (50 kg/hl of whole oats and 19 to 22 kg/hl of rolled or crimped oats).

Corn is the grain with the highest energy value (1.30 UFC/kg DM, about 30% more than an equal weight of oats), but the crude protein content is the lowest (66 g MADC/kg DM) and is unbalanced

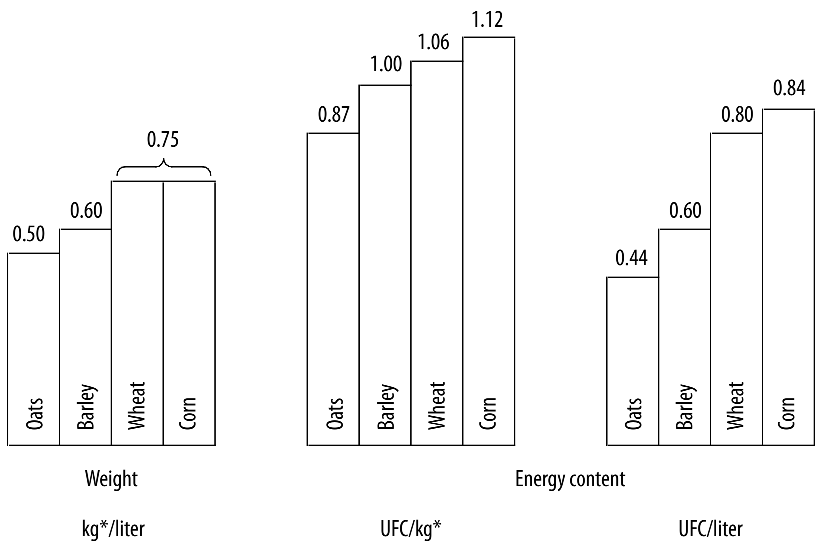

Figure 9.2. Difference in weight (kg per litre) and the energy value (UFC per kg or UFC per litre) of the major cereal grains.

in essential amino acids (deficient in lysine and tryptophan). Its nutritive value varies little. It can be utilised advantageously as long as the crude protein and minerals are balanced in the ration that it is incorporated into.

Barley is the cereal of compromise (Figure 9.2). It has an energy and protein value (1.14 UFC and 82 g MADC/kg DM) intermediate between those of oats and corn. It is the most commonly fed grain, but sometimes as germinated barley to over-worked or convalescing horses because of its soothing property in the digestive tract. Barley has a relatively variable nutritive value that corresponds to whether it is winter barley (6 row winter barley) which is high in crude fibre and lower in energy or if it is 2 row winter barley or spring barley which are lower in crude fibre but have a higher energy value.

Wheat would probably be the ideal grain with its energy value almost as high as corn (1.23 UFC/kg) and protein value (85 g MADC/kg DM) similar to oats, but it has the reputation for being heating and causing colic, laminitis and myoblobinuria (Chapter 2). The tradition of feeding grain to animals on the basis of volume instead of weight could be the reason for these major digestive disorders (Figure 9.2). As a precaution, limiting the quantity of wheat offered (0.5 kg wheat per 100 kg bodyweight per day) and feeding only small amounts at a time can prevent developing gummy balls in the stomach from the high gluten content. Recent research studies at the IFCE Research Station at Chamberet showed that with a well-controlled diet it is possible to feed 1.0 to 1.5 kg wheat per 100 kg bodyweight in 3 meals to young horses.

Rye, sorghum and rice were used for work horses around the turn of the 19^{th} century. They have high starch content, intermediate between barley and corn, and the crude protein content is close to wheat for sorghum, and close to corn for rye and rice (Chapter 16). Sorghum and rice are sometimes fed in the United States and South America. In the absence of any recent research on these grains, it is not possible to make recommendations on their use.

Triticale, a hybrid from a complex crossing of soft and hard wheat with rye, can be used like barley or oats.

Practical observations on the nutritive value of grains.

An additional simple measure of density is through direct observation of the proportion of endosperm in the grain. Good grain is shiny, bright, without disagreeable odour, and does not contain foreign objects: foreign seeds, debris from husks or straw, dust and soil. The most common toxic seeds are corn cockle (*Agrostemma githago*) and darnel (*Lolium temulentum*) (Section 9.3.1). Maximum tolerable levels are 2% for corn cockle and (or) 3% for darnel of inert seeds.

The grain density is measured in a conical hopper. In practice, it is of particular interest in order to determine the nutritional value of oats. A low density oat is the result of insufficient development of the endosperm, the most nutritious part of the grain. Kernel development can be directly determined by dissecting and weighing the bran and endosperm separately. With a good oat, the endosperm represents 70% of the total weight of the grain. Excessive density in oats (more than 60 kg/hl in contrast to 45 to 55 kg/hl for normal oats), however is considered unfavourable (humidified oats).

Contamination of grains diminishes their feed value and can be the cause of complete refusal. It can in some cases be the origin of severe disease (Section 9.3). It can indicate contamination by pests: weevils, angoumois grain moth, and European grain moth; and by fungus: corn smut and smudge destroy the starch in the grain, and smudge gives the grain an odour of rotting fish. Also, contamination by *Fusarium roseum*, which mostly affects corn, causes mycotoxicosis of the estrogenic or gastro-intestinal type (Section 9.3.2).

Abnormal odours can cause feed refusal by horses: mouldy odours, steamed odour (after thermal treatment for parasites or for reducing moisture), insecticide odours or mouse odours.

Processing of grains

Hard grains like barley or corn should be rolled or cracked before feeding; they are poorly consumed whole by performance horses in particular. This processing is also commonly used for oats. It does not improve overall digestibility very much (Chapter 12). However, it can have a beneficial effect for gluttonous horses or those with poor dentition.

Grains can undergo other processing (Section 9.2.3) notably thermal techniques: cooking with dry or humid heat or extrusion (pressure treatment after steam injection) or expansion (extrusion with extreme compression).These treatments do not significantly improve the overall digestibility of a complete feed when there are grains incorporated, but it can increase small intestinal starch digestion and consequently improve the energy content under certain circumstances (Chapter 12). The energy values can be found in the tables of Chapter 16.

Grains can be used in the making of traditional preparations of which the most common are mashes (singular mash). The grains are cooked in boiling water, with the addition or not of bran, linseed, salt, sodium bicarbonate, and well in advance of feeding (generally the night before feeding). These preparations are laxative and often fed before a day of rest. They can result in demineralisation if they are heavy in wheat bran and fed too frequently.

Sprouted grains and hydroponic forages prepared in germination containers can be of particular dietary interest for horses with frequent digestive problems: horses with inflamed digestive mucosa, problems with constipation or horses with poor appetite. They are equally useful as a delicacy for competition horses. It is important to remember that the germination is accompanied by important nutrient losses that are partially compensated for by minimal photosynthesis when the plant is very young. Therefore, this is an uneconomical feeding procedure that can neither be justified to meet dietary needs and cannot be recommended for a breeding farm or equestrian centre.

9.2.1.2 Grain by-products

Grains undergo multiple treatments before being used for human consumption in the form of flours (wheat, rye, etc.), starch (corn) and beer (barley). During this time, different by-products are produced: whose nutritive value and conditions under which they are used depend closely on the type of treatment the grain was subjected to.

Wheat feed flour, middlings, bran or millfeeds are the most common. They are interesting feedstuffs, because they maintain an elevated protein value after treatment (more than 126 g MADC/kg DM) and they are good phosphorus and magnesium suppliers. Wheat feed flour is high in starch (30 to 70%) and is an excellent source of energy. They can be incorporated in a relatively important proportion in compound feeds when they are relatively coarsely ground. Wheat middlings are the milling by-products with the least amount of semolina. It has a lower energy value than wheat feed flour, because of their limited starch (30 to 50%) content and a crude fibre content that is 3 to 4 times higher (10%). Further distinction within wheat middlings are the white fine or superfine wheat (UK), the wheat shorts (UK) or weatlings (USA, for all these milling wheat by products) which have crude fibre contents of 6 and 10%, respectively. Wheat bran has a lower energy value than the previously mentioned by-products because it has high crude fibre content (10 to 12%) and lower starch content. Finely ground bran is more digestible than coarsely ground. These by-products should not constitute more than 20-30% of the diet, particularly those high in cereal grain, to avoid further imbalance of the calcium/phosphorus ratio.

Corn starch is of interest as a source of energy (1.49 UFC/kg DM), especially for the high performance horse, when it is incorporated into a compound feed. Sweet corn waste is a by-product composed of cobs and residual kernels from ears of sweet corn which has been processed for human consumption. This by-product contains 47% husks, 31% cobs and 22% various fractions. After mechanical separation and sorting of the part destined for conservation, the waste is ground and pressed. Ensiling is the only method of conserving being used because of the high content of soluble carbohydrates in the by-product. Its energy value is around 0.70 UFC/kg DM but its protein value is low at around 35 to 40 g MADC/kg DM. The diet should be balanced with minerals and vitamins. This by-product can be used for animals with limited requirements after 2 to 3 weeks of adaptation. The level of consumption is limited: 1.0 kg DM/100 kg bodyweight due to the low dry matter content (20-22%).

Brewers and distillers waste have a high protein value (250 g MADC/kg DM) and a satisfactory energy value (0.79 UFC/kg DM). However, they cannot easily be used fresh for the horse, because it is difficult to preserve them.

9.2.1.3 Legume seeds

Horses can consume the protein-rich seeds as is (faba beans, peas, lupines, etc.) when they are fed as a complement to a ration rich in cereal grains. Faba beans have been used in horse diets since the last century in Europe, but the sweet white lupine can be used equally well, at 0.5 kg per 100 kg bodyweight per day. Their protein value is high (128 to 316 g MADC/kg DM) and the proteins are fairly well balanced in essential amino acids, except the sulphur amino acids and in the case of lupines in lysine and tryptophan. They are poor in calcium and magnesium. Lupines are very rich in manganese. Faba beans have been used with success in the past, notably for horses in intense work (hunt horses, commercial carriage horses). Peas were also frequently fed to horses during times when the faba bean harvest was poor. Pea pods also entered into the diet because they provided crude protein, potassium and calcium. However, vetches (*Vicia cracca* and *Vicia sepium)* are toxic and should not be included in the diet of the horse (Section 9.3.1).

9.2.1.4 Oilseed by-products

Oilseed meals, residues of the oil industry for human consumption, are obtained by extraction of oil from the oilseed by pressure (expellers meal), or with the help of a solvent (solvent extracted meal) after an optional dehulling of the seed, particularly in the case of peanut or sunflower. They are all rich in crude protein (90 to 450 g MADC/kg DM), well balanced in amino acids except sometimes in the sulphur amino acids. They have a high energy value (0.59 to 1.02 UFC/kg DM) and they are good phosphorus and magnesium suppliers. They are often used to balance diets that are lacking in crude protein through incorporation in commercial compound feeds or sold separately for mixing with cereal grains.

Linseed (flax) meal (267 to 274 g MADC/kg DM) is very commonly used in horse diets because of its laxative properties on the digestive tract of the overworked horse, particularly overfed with oats and for the softness and brilliance it gives to the coat. Before feeding, it should be soaked in hot water or cooked to prevent release of hydrocyanic acid which is toxic for the horse (Section 9.3.1). Intake should be limited to 0.3 kg per 100 kg bodyweight per day.

Soybean and peanut are also commonly used meals. They are rich in crude protein (420 to 450 g MADC/kg DM), well balanced in amino acids except the sulphur amino acids (methionine and cystine), which makes them particularly suitable for growing foals and lactating mares. Sunflower meal can be use instead, when the price increases, but it is lower in crude protein (223 to 273 g MADC/kg DM) and poor in lysine. It must be dehulled to have a satisfactory energy value. Its nutritive value is relatively variable depending on the harvesting conditions and the processing that it is subjected to in the oil industry. Rapeseed meal could not be used because it contained undesirable products (glucosinolates and erucic acid) and poor palatability. A new variety of rapeseed called double zero rapeseed or canola does not contain these undesirable products. Its protein value is of interest: 286 g MADC/kg DM. Copra and palm kernel meals are mostly used to support the incorporation of molasses in compound feeds.

9.2.1.5 Industrial protein sources

Urea used as a non-protein nitrogen source is a lot less toxic to horses than to ruminants (about 4 times less), however formation of ammonia or ammonium salts are the problem. Therefore the rate of incorporation of anhydrous ammonia (NH_3) should be 3% maximum for the treatment of straw that will be used in feeding horses.

9.2.1.6 Fruits and their by-products

Carob is the fruit of a tree in the legume family, the carob tree. The seed is very rich in carbohydrates (starch and sugar) making up 45% of the dry matter. Its energy value is 0.74 UFC/kg DM. It is, however, poor in protein (17 g MADC/kg DM) and minerals. Carob is very palatable to the horse and can be consumed at up to 1.2 kg per 100 kg bodyweight per day, but the digestibility of the seed is limited. Commercial compound feed manufacturers will incorporate it in its horse formulations in generally low amounts (from 3 to 10%). Also the dried pulp can be used.

Apple and pear pomace and rarely grape pomace are from the fabrication of alcohol and contain, respectively, 15 to 20% and 30 to 35% DM per kg of fresh product. They can be used mixed with bran, chopped forages and molasses, in case of a shortage of feed. They are sometimes incorporated in minimal amounts in certain formulations of compound feeds, after dehydration. These are palatable, and are rich in sugar as well as crude fibre. Grape pomace also has a very high lignin content which really limits the digestibility and, consequentially, much interest. These feedstuffs in general have mediocre nutritive value and consumption should be limited to 0.5 kg of fresh pomace per 100 kg of bodyweight per day because their alcohol content can reach 100 g/kg DM.

Fresh fruit pulp is the by-product of commercial fruit juice production or some liquors that is used also with success in the diet of the horse. They possess low crude protein content but presumably have a high energy value. They are well accepted and tolerated by the digestive tract. They are sometimes incorporated after dehydration in compound feeds.

9.2.1.7 By-products of animal origin

Non-fat dry milk was used successfully in the past for feeding the lactating foal. It has been replaced with powdered milk incorporated into milk replacer specific to the requirements of the horse. In case of emergency, however, milk replacer for calves and piglets can be used if it is adjusted for mineral composition and carbohydrate content in accordance with mare's milk (Chapter 3, Section 3.2.4.3 and Chapter 5, Section 5.4).

Lactose, in the form of ultra-filtrated dried whey, can be used in the feeding of foals before or after weaning (until 12 months), as long as it is incorporated into a concentrate feed. The inclusion rate cannot exceed 40% because of problems it can cause with the manufacturing of the feed (too hard). It allows the horse that is growing or gaining weight to achieve very high weight gain.

Fats, animal (tallow, etc.) or vegetable (oils of sunflower, corn, soybean, coconut, etc.), are now commonly part of the diet of the horse, particularly those used for endurance riding. Fats have very high energy values (2.90 UFC/kg DM for animal fat and 2.96 UFC/kg DM for vegetable oils). They are very digestible, particularly vegetable fats, and are fairly well accepted by the horse when they are mixed into a compound feed at a rate of 10 to 15% (Chapter 6). Oils from rapeseed (canola) and especially from soybean and sunflower are very high in C18: 2w-6 fatty acids (20 to 65% of the total fatty acids) and in C18: 2w-3 (7 to 10% total fatty acids) for canola and soybean (Chapter 16: annex 6). They are much more palatable than animal fats.

In terms of conservation, fats and oils are susceptible to rancidity because they are easily oxidised, even more so if they are unsaturated: such as vegetable oils as opposed to animal fats. This is why feed manufacturers add antioxidants to feeds where fats are incorporated.

9.2.2 Compound feeds

The animal feed industry produces two types of compound feeds for horses:

- complete feeds include all of the nutrients necessary in adequate amounts to cover the requirements and can be completely substituted for the traditional ration;

- complementary feeds are used most often to replace the traditional concentrate feedstuffs (ex: oats) to better balance the forages.

9.2.2.1 Composition

The major raw materials (e.g. feed materials according to EU regulations) used in feed formulation are the following:
- high energy feedstuffs: grains (oats, barley, etc.) and their by-products (bran, middlings, germ) mainly; carob, fruit pomace, molasses incidentally;
- high protein feedstuffs: soybean meal, linseed (flax) meal, sunflower meal, rapeseed (canola) meal, safflower meal, sesame meal and legume seeds;
- High fibre feedstuffs: alfalfa meal, grass hay, straw, cereal grain hulls.

Every formulation is completed with added premix that has, for one part, the essential vitamins for the horse (Chapter 1) that are poorly represented in the raw materials previously named (vitamin A, D3, E and, sometimes the B vitamins) (Chapter 12) and for the other part, minerals that are balanced for the mixture and (or) the diet (Chapter 2, 12 and 13).

9.2.2.2 Characteristics of complete feeds

They are generally 11 to 14% protein (crude protein is designated on the feed tag), to 15 to 20% crude fibre and 10 to 12% minerals (crude ash). Some feeds for race horses have very low fibre content (12 to 13%). their energy values vary from 0.80 to 0.90 UFC per kg DM (0.70 to 0.79 UFC per kg feed). They contain 3,500 to 8,000 IU of vitamin A and 1000 to 3,000 IU of vitamin D3 per kg of feed.

These feeds are balanced in minerals and vitamins. They have the advantage of improving the condition of the animal and avoiding the hay belly that happens when consuming poor quality hay. Their use should be carefully matched to the type of animal, the nature and importance to meet the nutritional requirements: lactation, growth, work (Chapter 3, 4, 5, 6 and 8).

9.2.2.3 Characteristics of complementary feeds

In general, these feeds have lower crude fibre (7 to 17%) but higher protein (crude protein) content (13 to 20%) than complete feeds, and contain 8 to 15% minerals (ash); also their energy value varies from 0.90 to 1.10 UFC per kg DM (0.79 to 0.97 UFC per kg feed). It contains 10,000 to 16,000 IU vitamin A and 2,000 to 6,000 IU vitamin D3 per kg feed. Mineral and vitamin feed supplements (or MVFS) is by definition also a complementary feed designed to balance the ration whether it is fed alone or whether it is incorporated in a complementary feed.

9.2.2.4 Labelling legislation and regulation

Like all compound feeds for animals, horse feeds are under the same labelling regulations defined on a national level plus those of other European nations to make them consistent with other nations in the European Union. Currently, the feed tag must state:
- Type of feed: complete feed, complementary feed, mineral feed, molasses feed, complete milk replacer feed, complementary milk replacer feed, and liquid complementary feed.

- Type of animal for which the feed is intended.
- List of feed materials without their percentages in the feed.
- Fixed number of required analytical guarantees on as fed basis, moisture content, crude fibre, crude ash, crude protein and crude oils and fats (Table 9.3).
- Additives used and in particular the added vitamins with their concentrations.
- Feeding instructions and name and address of the manufacturer.
- Date of manufacture.
- Expiration date expressed in the form 'best before,…' which takes into account the minimum storage life of incorporated additives (e.g. vitamins, etc.).
- Chemical additives used during the manufacture such as preservatives, antioxidants and colorants.
- List of additives such as probiotics, prebiotics, yeast are only optional. This is regulated by European directives. It cannot be done by the feed manufacturer if there exists for these additives an official analytical method or at least a scientifically recognised analytical method.

The label provides some coded information that is important technical details on the reasonable use of the feed. The analytical guarantees can be criticised for only giving the average amounts of the different constituents but are subjected to the established margins of tolerance.

9.2.2.5 Observations on the formulation of these feeds

Two formulation procedures can be used for making a compound feed. In the first instance, the manufacturer uses linear programming to produce a least cost formulation; this is also the procedure

Table 9.3. Required listing of the amounts of some analytical constituents of compound feeds.[1]

Analytical constituents	Complementary feeds			
	Complete feeds	Generic	Specific	
			Molasses	Mineral
Moisture	+	+	+	-
Crude protein	+	+	-	-
Crude fibre	+	+	+	-
Crude ash	+	+	+	-
Calcium				
≥5%	-	+	-	+
<5%	-	-	-	+
Phosphorus				
≥2%	-	+	-	+
<2%	-	-	-	+
Sodium	-	-	-	+

[1] + : obligatory: average values with established margins of tolerance; - : optional.

generally used for most livestock compound feeds. In this case, the type of the feed materials and their proportions can change, but the general nutrient intakes for a given formula remain in theory constant. In the second case, the manufacturer maintains a fixed formulation (type and proportions of feed materials); this assures a greater consistency in the compound feed. In the case of the horse, many manufacturers opt for the second method of formulation.

9.2.3 Processing of feed materials and compound feeds

9.2.3.1 Cereal grains

The hull of cereal grains is generally an obstacle to the action of digestive agents. This is the reason for subjecting the cereal grains to simple processing: grinding, cracking, rolling, soaking to allow easier contact of different parts of the grain with digestive enzymes. The various treatments are thought (Table 9.4) to degrade not only the hull of the grain but also certain constituents, notably the starch fraction of the grain.

All of the treatments aim to improve overall starch digestibility of cereal grains. They are designed to destroy the physical-chemical structure of the starch granule to release the chains of amylose and amylopectin that are easily hydrolysed by the digestive enzymes of the small intestine, and produce glucose, or for the enzymes of the bacteria of the large intestine to produce propionic acid, under the conditions of use (Chapter 1 and 12). This can change the energy value of the grains, which is reflected in the tables (Chapter 12).

The effect of processing on the digestive and metabolic utilisation of cereal grains is explainable both by the degree of complexity of the structure of the starch granule and the relative proportions of starch that are digested rapidly, slowly or resistant (Table 9.5). Processing is more effective than the granular structure is complex: as with the example of corn. Heat treatments at high temperature (for example extrusion) are of interest because they increase the proportion of rapidly digestible starch by causing strong starch gelatinisation (Table 9.5).

The recurring question that is posed is the following: which are the most appropriate treatments? The response should be cautious because of the effects on the proportion of starch digested in the small intestine varies according to the botanical origin of the cereal grain, the treatment it undergoes and the quantity of cereal grain consumed (Chapter 12, Section 12.1.3.2).

It is possible to say that oats can be used in either form, whole or rolled, barley also in the rolled form or preferably ground, but corn is best thermally treated (popped, extrusion or expansion). The presentation in the form of pellets could in the case of corn reduce the proportion of the starch digested in the small intestine.

9.2.3.2 Cereal by-products

Cereal by-products come mainly from the milling, starch, semolina, and fermentation industries. Wheat by-products consist primarily of the poorly digested hulls of grains and the protein-rich inside layer of grain wall (e.g. aleurone layer) after different mechanical processing. They can be categorised in order of increasing cell wall content: wheat feed flour (4% of grain), wheat middlings

Table 9.4. Characteristics of the major treatments for cereal grains (adapted from Mercier, 1969).

Treatments	Crimping or grinding	Cooking under pressure	Steaming short duration then rolling	Steaming long duration then rolling	Extrusion without steam then pressure	Extrusion with steam then pressure	Micronisation	Vacuum without steam	Pelletizing
Cereal grain treated	corn, sorghum		corn, sorghum, barley, oats, wheat	corn, sorghum, barley, wheat	corn	corn, sorghum	sorghum, wheat, barley	sorghum, barley	
% moisture before treatment	10-12		8-12	8-12	13		12-14	12-14	
Treatment: particle state, temperature, duration of treatment, %moisture	Milling with hammer mill	grain steam: 5.6 kg/cm^2 for 1.5 h; flattened between rolling corrugated cylinders	grain steam: atmospheric pressure for 3-5 min; flattened between rolling corrugated cylinders	grain steam: atmospheric pressure for 25-30 min; temperature 100-120 °C; flattened between rolling corrugated cylinders	grain passage: under pressure in a machine type 'meat grinder'; temperature: 93 °C	grain steam: pressure 21 kg/cm^2	grain action: electro-magnetic short waves from infra-red in 20 sec; flattened between rolling corrugated cylinders	grain action: under pressure vacuum without steam; temperature 250-300 °C	machine; pellets high in molasses
% moisture after treatment	10-12			wheat: 16; corn: 18; sorghum: 20	12.5		2	10-12	

Table 9.5. Proportions of different starch fractions for cereal grains and whole potatoes that are extruded at high (HT) or low (LT) temperature (adapted from Murray *et al.* 2001).[1]

Ingredient	Treatment	RDS	SDS	RS	TS
Barley	Whole	23.2	11.4	17.0	51.6
	LT	30.3	13.5	4.8	48.6
	HT	47.8	4.4	6.0	58.2
Corn	Whole	34.6	14.6	23.6	72.8
	LT	54.2	13.1	6.4	73.7
	HT	65.0	7.8	1.4	74.2
Wheat	Whole	15.5	33.6	13.0	62.1
	LT	54.6	6.0	6.1	66.7
	HT	65.5	5.2	0.6	71.3
Sorghum	Whole	27.3	13.0	33.8	74.1
	LT	49.1	10.9	15.4	75.4
	HT	70.0	5.4	2.1	77.5
Potato starch	Raw	24.4	2.6	60.0	86.9
	LT	65.4	27.0	2.2	94.6
	HT	-	-	-	-

[1] RDS = rapidly digestible starch; SDS = slowly digestible starch; RS = resistant starch; TS = total starch: RDS + SDS + RS; LT = 83 °C<T<94 °C; HT = 135 °C<T<145 °C.

(or midds): superfine, fine (5% of grain) and shorts (3% of grain), fine and coarse bran (5 to 7% of grain respectively).

There are a variety of corn by-products available because of the complex wet processing technology used by the starch industry (Figure 9.3). These are the most commonly used in horse feed:

- Corn bran is made of the wall (pericarp and aleurone layer) and tip caps of the grain which includes fragments of starch, a part of the aleurone layer and a small portion of the germ, water used during processing. Crude protein and crude fibre content average 13% and 15%/DM respectively; cell walls are slightly lignified and easily degradable.
- Gluten feed comes from the steep liquor (corn solubles fraction) left from the wet milling separation of starch from the grain and then separation from the germ and the hulls; average protein and crude fibre content is 22 and 9%/DM, respectively, (their level of ingestion is limited in the horse). It is the most often commercialised in dry form after pelletizing.
- Gluten meal comes from the separation of the protein fraction from the horny albumen. Crude protein content is very high (68% DM).
- Finally starch and glucose.

The main barley by-product which is sometimes fed to horse is barley rootlets that have good crude protein content (14% DM).

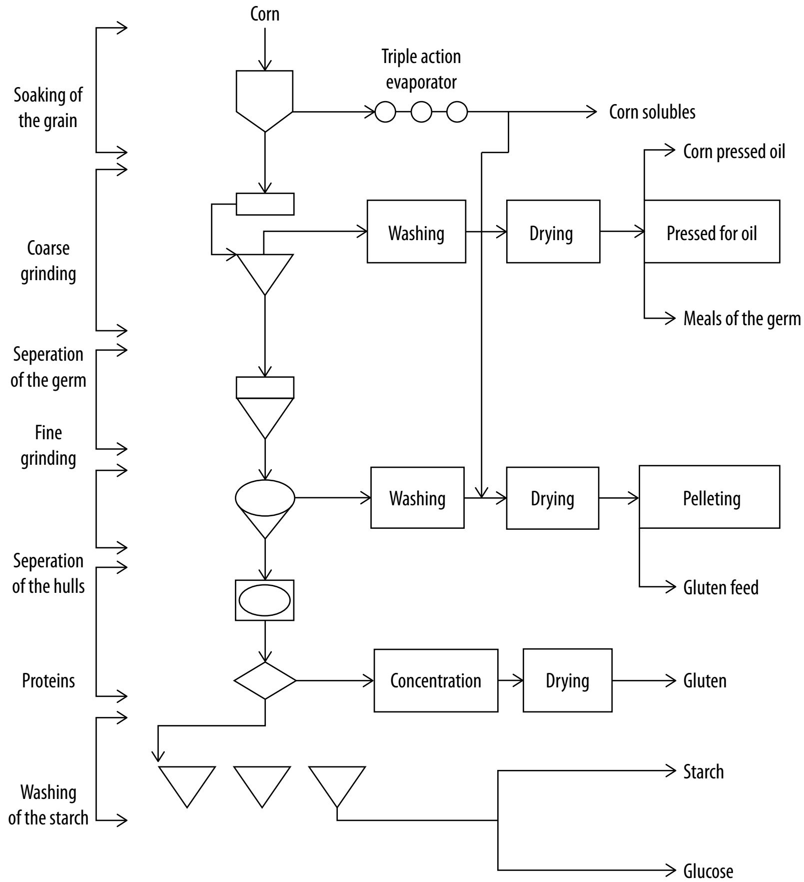

Figure 9.3. General diagram of corn starch wet extraction (INRA, 1988).

9.2.3.3 Oilseed meals

Meals are by-products from the industry that extracts oils from fruits or oil seeds using complex processes (Figure 9.4). Two main processing methods are distinguished:

- Extraction by pressure that produces a meal called expellers containing 5 to 10% fat.
- Extraction with the aid of a solvent that produces a meal called defatted containing less than 4% fat.

Shelling or dehulling the seeds is done before beginning treatment to get rid of the highly fibrous shells or hulls and also to obtain a higher protein product: for example, sunflower seeds. The same type of meal can have different nutritional value, notably protein, depending on the type of processing it is subjected to. This is why the name is commonly accompanied by the name of the treatment: expeller, defatted, dehulled.

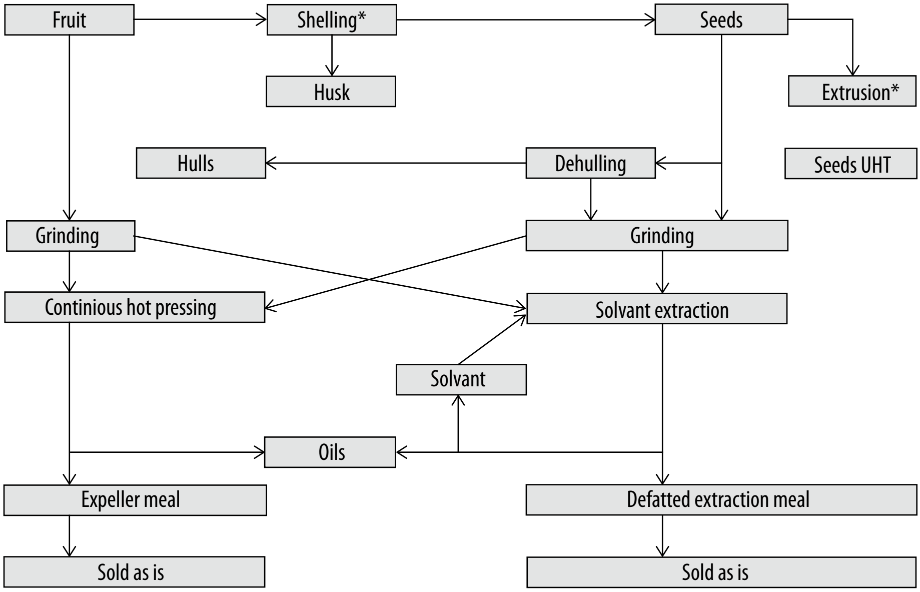

Figure 9.4. General diagram of the processes used in making oil meals (INRA, 1988). * Operations carried out only for certain products.

9.2.4 Dietetic feeds and nutritional supplements

9.2.4.1 Dietetic feeds

According to their initial composition and nutritional characteristics or the method of preparation, dietetic feeds serve to prevent digestive troubles (absorption, assimilation) or metabolic issues from temporary disruption of nutritional status (Table 9.6). These feeds are not used to nutritionally balance a ration, which should be established on the short and medium term by appropriate rationing

Table 9.6. List of the specific objectives and permitted use of dietetic feeds (Appendix of the European Directive 2008/38: EC, 2008a).

Compensation for chronic insufficiency of small intestinal function
Compensation for the chronic digestive disorders of large intestine
Reduction of stress reactions
Compensation of electrolyte loss in cases of heavy sweating
Nutritional restoration, convalescence
Support of liver function in the case of chronic liver insufficiency
Support of renal function in the case of chronic renal insufficiency

(Chapter 1, 2 and 13) as a normal horse, even if dietetic feeds represent a significant proportion of the daily ration.

They clearly differ from ordinary or standard feeds: complete or complementary feeds and medicated feeds as defined by the directive of the European Council 90/167/ECC (Medicated Feedingstuffs: EC, 1990). Accordingly, dietetic feeds should be specific to particular pathological states when it comes to nutritional status: that is to say to meet specific nutritional needs.

Dietetic feeds never include chemical additives that have pharmaceutical-dynamic, anti-infectious or anti-parasitic properties. The nutritional characteristics and composition of dietetic feeds should correspond to the recommendations included in the Appendix of the European Directive 2008/38 (EC, 2008a) and they can be used without a veterinary prescription. But the advice of a veterinarian can be very useful since these feeds are intended to prevent health problems.

Their original nutritional characteristics should be controlled by the official methodology or at least by established scientific methodology, regarding the following constituents: fibres (total, soluble, insoluble), amino acids (for example tryptophan), essential fatty acids, trace minerals (iodine, selenium) and vitamins (pyroxidine and biotin). The authorised objectives of dietetic feeds must be clearly visible using the official terminology established and disseminated by the European Commission.

9.2.4.2 Nutritional supplements

Nutritional supplements partially overlap the categories of concentrate and standard feeds (compound feeds), dietetic feeds and additives. Further, their position is not totally established. Nutritional supplements are concentrated feedstuffs consisting mostly of carbohydrates, amino acids, highly digestible fibre, fats, electrolytes, trace minerals, vitamins, and pH regulators roughly combined in a variety of mixtures. They do not represent an important part of the daily ration and they are fed for short periods of time.

Nutritional supplements are used in small quantities either by adding to the daily feed, or diluted into the drinking water to meet temporary change in nutritional requirements: critical changes in nutritional status (breeding, weaning, and rapid growth, rearing conditions, etc.), significant increases in work or changes in diet. Other occasional circumstances that could be of concern: change in weather, painful transport, consequences of parasitic treatments, vaccinations, subclinical infections, heavy medication treatments or long convalescence. However, their efficacy and security are not clearly established in terms of performance, well-being and accumulation of residues in the food chain.

European regulations of feedstuffs do not give specific definitions for nutritional supplements. However, they are considered by most of the member countries as complementary feedstuffs because they do not satisfy all of the daily nutritional requirements.

9.2.5 Feed additives

Feed additives are substances, micro-organisms or preparations other than feed materials (or ingredients) and premix, that are intentionally added to the feed or water to:

- improve the characteristics of the feeds;
- improve the characteristics of animal products;
- satisfy nutritional requirements of the animal;
- improve the effects of environmental conditions on animal production;
- improve animal production; performance or well-being (gastro-intestinal flora, feed digestibility).

Four categories of additive are considered in horses: technological, sensory, nutritional and zootechnical. Within each category are different groupings. Feed additives are recorded in an official European list called: European Community Register of Feed Additives (EC 1831/2003; EC, 2003-2008b). This list is exclusive for different types of animals and available on the internet (EC, 2008b). Feed additives require authorisation from the European Commission before marketing. A technical dossier for authorisation is submitted to the European Commission of Industry and the safety is evaluated by the European Food Safety Authority (EFSA).

9.2.5.1 Technological additives

These additives are used by the animal feed industry to preserve the technological stability of products, nutritional value, palatability and reduce spoilage during storage to preserve the health of the horse. Non-nutritional additives are used for their technological properties to strengthen physical characteristics of feed products.

Binding and anti-caking agents are mixed with feed materials to improve the cohesion of the finished feed without increasing hardness. Antioxidants and preservatives are also mixed with feed materials to prevent oxidation of feed materials and vitamins. Colour and aroma can be preserved with authorised additives. Other additives can be added to reduce dust or maintain a uniform dispersion of emulsifying agents with certain components (fats or oils) in the liquid portion of a feed. Oxidation of free mineral complexes is limited and stability of the finished feed is improved with the use of sequestering substances.

9.2.5.2 Additives influencing health and performance

Nutritive and non-nutritive substances are sometimes added to the ration to improve the horse's health. But there is still a great debate over their definition and efficacy. With humans, the terminology is not established: they are called 'nutraceutical' or 'functional food'. In horses they are commonly called feed additives. Very few are actually approved for use in the horse, as can be seen on the list established by the European Commission (EC, 2008b).

Enzymes

Exogenous enzymes are produced by industry. They are only effective if they are not affected by processing during the manufacture of feeds or during digestion in the animal. They can improve digestion, prevent appearance of digestive disturbances, and limit the effect of phytates on the absorption of some minerals. There are no enzymes actually registered and therefore they are not authorised for use in the horse in Europe;

Probiotics

Probiotics are live bacteria that are selected, concentrated and dried to be fed continuously because they cannot grow in the intestinal tract. The most common are *Lactobacillus bifidobacteria, Streptococcus faecium* and *Bacillus subtilis*. These bacteria should not be affected by digestive secretions. They should resist predatory bacteria in the digestive ecosystem of the host animal, which use the nutrients produced by the digestion of feedstuffs in the host animal and at its expense produces ammonia and amines and sometimes bacterial endotoxins. Probiotics are capable of inhibiting pathogen bacteria such as *Salmonella*. Probiotics also provide vitamins, increase the production of volatile fatty acids and enzymes that stimulate digestion in the large intestine.

Yeasts

This product consists of live yeast. They are mostly from *Saccharomyces* spp. and notably *Saccharomyces cerevisiae* and *Aspergillus oryzae.* They are used in dry or concentrated form with a cellular content of 10^9 concentration of live yeast. Yeasts are of interest for use in horses receiving very high starch diets because they reduce lactate production in the large intestine and improve protein digestibility. However, the effects on animal performance still needs to be confirmed. Yeasts may limit the duration and severity of enterocolitis. Their potential efficacy is best if fed on a continuous basis. There are actually two yeasts that are registered and authorised for use in the horse in Europe.

Prebiotics

These are oligosaccharides that are resistant to the digestive enzymes in the mammalian small intestine; but rapidly fermentable by bacteria present in the large intestine. They are polysaccharide complexes: fructooligosaccharides, mannose or glucomannanes. Prebiotics promote growth of the bacterial microflora in the large intestine and limit the adherence of pathogenic bacteria to the intestinal wall. Fructose or galactoses stimulate the growth of beneficial bacteria such as *Lactobacillus* or *Bifidobacteria* at the detriment of deleterious bacteria like *Clostridia*. Their effects should be further confirmed in the horse because most of the studies have been conducted on humans. In general, prebiotics are considered by the members of the European Union as feed materials (simple concentrate feedstuff or ingredients). Therefore, they do not require authorisation of the European Commission as additives.

Organic minerals

Organic trace minerals are linked to a large spectrum of ligands while the inorganic sources are linked to oxide, sulphate, chloride or carbonate ions (Chapter 1-12 and 16: Appendix 3). The principle ligands consist of amino acid complexes, polysaccharides or proteins of various sizes (proteinates). The metal ion availability from inorganic sources is very variable: high and limited respectively for sulphide and oxide salts. The availability of organic sources should be equal or greater than that of inorganic sulphates to be of any interest. No difference in biological utilisation and animal performance has been demonstrated in the horse between the two sources of minerals.

Glucosamine, chondroitin and methylsulfonylmethane

Glucosamine is an amino monosaccharide. Chondroitin sulphate is a sulphated glycosaminoglycan composed of alternating disaccharide units, glucuronic acid and N-acetylgalactosamine. These compounds are thought to have protective properties for articular cartilage and repair of osteoarthritic lesions when used alone or in combination. However, there is not clear proof of their efficacy and safety with their use over the short or mainly over the moderate term. Methylsulfonylmethane (MSM) is a source of readily available sulphur that is thought to have a protective role in cartilage. Glucosamine, chondroitin and MSM are considered feed materials, but they could be introduced to the additive or medication lists if a claim was lodged for the corresponding applications of these products.

Fatty acids

Linoleic acid (C18:2,n-6) and α-linolenic (C18:3,n-3) are essential fatty acids for which the requirements have not yet been established in the horse. The omega double bond in 6^{th} position (linoleic acid) – omega-6 – or in the 3^{rd} position (linolenic acid) – omega-3 – confers anti-inflammatory properties in other species. These properties are yet to be demonstrated in the horse.

Antioxidants

They are currently being studied in the equine athlete because they are supposed to limit oxidative stress (reactive oxygen species = ROS), and chronic airway obstruction (recurrent airway obstruction = RAD). The activity of different mineral-dependant enzymes or mineral-dependant non-enzymatic antioxidant are involved, as well as other compounds (vitamins A, E, β-carotene, lutein and lycopene) could be involved in the complex process. Also their efficacy needs further exploration.

Ergogenic aids

These are nutritional substances that are not essential as they are commonly involved in normal metabolic processes. Ergogenic substances try to compensate the deficit level of a substance supposedly meeting the insufficient endogenous production that limit the efficiency of muscle metabolism. This argument does not justify supplementation. In fact, their effects have not yet been clearly demonstrated in humans or horses. Furthermore, creatine and gamma-oryzanol are not authorised and are not found on the European Community register (EC, 2008b).

Growth factors

Some antibiotics and ionophores used as growth factors in cattle (e.g. monensin) or as coccidiostats in poultry (e.g. lasalocid, narrasin) are responsible for deaths in horses from the size of dose that are regularly used in these other species. A collective poisoning was seen in France from narrasin that was mistakenly mixed into a commercial concentrate.

Herbal preparations

These plants do not contribute to the nutritional content of the ration. They are used with the expectation of preventing or treating disease. Their efficacy and safety have yet to be clearly demonstrated. Extrapolation from observations in other species are very risky because the data on induced acute or chronic toxicity remains to be measured for most plants. In addition, there may be interactions between them if several are used together or/and with prescription medications from a veterinarian for treatment of other diseases.

Medicated feeds

These feeds are a mixture of a feed and a veterinary medicinal premix (Directive 90/167: EC, 1990). Only medicinal premixes authorised at the national or European level can be used. Their production is reserved exclusively to registered manufacturers and must be prescribed by veterinarians.

9.2.6 Feed contamination from doping substances

Feeds for competition horses can be naturally contaminated (compounds contained in the raw materials) or inadvertently included during the manufacturing process, transport or packaging by the compounds or plants that contain substances prohibited under the regulations are described in Chapter 6.

A list of the most commonly found contaminants in Europe and plants that contain them has been established (Table 9.7), this list does not include all substances because some, like hordenine or lupinine for example, can also cause problems. These plants should be excluded from the horse's diet and their presence controlled in feed materials or 'finished' manufactured products because the amount of these substances that can interfere without showing a positive anti-doping test have been established experimentally (Respondek *et al.*, 2006) but not yet formally implemented.

In this spirit, international anti-doping control official laboratories are working together to standardise the limits of detection of these contaminants in urine or blood from race and sport horses. Once the limits have been finalised and a maximum level of residue of contaminants in urine and/or blood set, a maximum level of contaminants in feeds can also be set as reference for quality control laboratories that are already in place in the chain of feed manufacturers quality controls processes. Meanwhile, it is imperative that users be attentive to the quality of feed and supplements used, asking suppliers if a contaminant control of the feedstuff has been done. Once the supplier has been contacted, further information can be found by contacting (in France) the Laboratoire des Courses Hippiques (Race Horse Laboratory LCH, Verrières le Buisson, France), which is the official anti-doping laboratory in France to perform these checks.

Table 9.7. Plants or feed materials containing contaminants (adapted from Bonnaire *et al.*, 2008).

Substances	Plants	Feedstuffs
Caffeine	cocoa beans, tea, cafe, mate, guarana, cola	all feeds that contain these plants or contaminants
Theobromine	cocoa beans	chocolate or feeds containing these plants (such as appetizers or contaminants
Theophylline	tea, cocoa	feeds or supplements
Atropine	datura, jimson weed	oilseed meals
Scopolamine	datura, jimson weed	oilseed meals
Morphine, odeine	poppy	alfalfa contaminated with this plant

9.2.7 Regulation

Feeds made by the animal feed industry are subjected to national and European regulations as follows. European legislation considers the horse as a production animal (food-producing animal), which is an animal destined in most cases to enter the food chain, even though the horse is not usually produced (let alone used) for this reason. This legislation is not limited to the information found on the feed bag label but also to other accompanying commercial documents. It also extends to internet sales. Legislation was increasingly updated in 2008: '*Regulation of the European Parliament and of the Council on the placing on the market and use of feed: proposal*'. The text has been finalised on13th July 2009 as Regulation (EC) No 767/2009 (http://ec.europa.eu/food/food/animalnutrition/index_en.htm).

The regulations distinguish:

- Feed materials. These are products of vegetable or animal origin, whose principal purpose is to meet animals' nutritional needs, in their natural state, fresh or preserved, and products derived from the industrial processing thereof, and organic or inorganic substances, whether or not containing feed additives, which are intended for use in oral animal feeding either directly as such, or after processing (processed foods or as components: ingredients), or in the preparation of compound feed, or as carrier of premixtures; A list of the feed materials is given part C of Commission Regulation (EU) No 68/2013 of 16 January 2013 Catalogue of feed materials combined with a list of undesirable substances: Commission Directive 2003/57/EC and Commission Directive 2003/100/EC (which amend Directive 2002/32/EC); and permitted tolerances for the compositional labeling of feed materials and compound feeds: Commission Regulation (EU) No 939/2010 20th October 2010 amending Annexe IV to Regulation (EC) No 767/2009. All these regulations and directives are accessible via the website mentioned above. The main feed materials are described in Section 9.2.1 of this chapter. Whole plants and medicinal plants are also considered as feed materials but the conditions of their use are described in Section 9.2.5.2 of this chapter.
- Compound feeds. These are a mixture of at least two feed materials, whether or not containing feed additives, for oral animal-feeding in the form of complete or complementary feed. They cannot make claims of having properties relative to pathological disorders. They are called standard compound feeds. Different types of compound feeds are considered:
  - complete feeds;
  - complementary feeds;
  - molasses;
  - mineral feeds;
  - milk replacers;
  - dietetic feeds.
- Additives included in compound feeds must be listed on the manufacturer's label (article 16; Directive 70/254: EC, 1970) (EC, 2008b) for antioxidants, preservatives, colorants, copper, vitamins A, D, E, enzymes and microorganisms. The other vitamins and minerals can be listed voluntarily by the manufacturer. Feed additives are recorded on a list called Community Register of Feed Additives (EC 18312003: EC, 2003, 2008b) revised on 12th February 2014. This list is exclusive for the different kinds of animals is accessible on the internet (http://ec.europa.eu/food/food/animalnutrition/feedadditives/registeradditives_en.htm).

Only harmless additives are authorised, such as nutritional factors (trace minerals, vitamins), preservatives (antifungal like sorbates or propionate), processing agents (binders, anti-caking agents, emulsifiers, etc.). Remember at this point, that the level of vitamin D must be limited to 4,000 IU/kg feed daily. EFSA is responsible for risk assessment beyond the stage of approval of additives (http://www.efsa.europa.eu).

It is very important to avoid all contamination from authorised additives of other animal species (poultry, ruminants) because they can be highly dangerous in the horse, or all antibiotics that can disturb the microbes in the large intestine: ionophores used like coccidiostats in poultry (lasalocid, narrasin), growth factor in ruminants (lasalocid, monensin), and active antibiotics against gram + bacteria, such as tetracycline, lincomycine. On the other hand, probiotics (lactic fermentations) are very well tolerated by the horse, and can help in regulation of fermentation in the large intestine.

The legislation list for European Community is displayed on the following website: http://ec.europa.eu/food/food/animalnutrition/legisl_en.htm.

9.3 Plant poisoning and feed-related poisoning

Feed poisonings can be seen in the horse after accidental ingestion of toxic plants (Table 9.8), feeds contaminated with diverse chemical residues (xenobiotics), mycotoxins or toxins of bacterial origin. They can be caused by adulteration of feeds or from feeding excessive quantities of certain feeds, as well.

9.3.1 Plant poisonings

In general, plant poisonings come from one of three origins: native poisonous weeds growing in the region; cultivated crops contaminated with anti-nutritional factors that are toxic to horses; or cultivated ornamental plants, particularly some trees and shrubs. Looking at the large number of toxic species, the theoretical potential of poisonings is great. However, when consulting field observations and statistics from poison control centres (for example: Veterinary School in Lyon, France) only a small number of plants are routinely implicated in toxic accidents. Other plants do not commonly result in toxic pathologies and they are rarely involved. The toxic potential of all poisonous plants should be kept in mind, even though only about fifteen are known to be of true concern.

The apparent distortion between theoretical toxicities and clinical incidence is tied to a number of factors:

- some plant have low toxicity and do not grow in great numbers, so this risk of the animal consuming a dangerous quantity is reduced (buttercup, wild mustard);
- some plants have a very limited geographical area of distribution;
- many toxic plants are commonly avoided by animals in a pasture except in times when the there is little else to choose from; then selectivity diminishes or disappears.

Certain plants may be avoided while they standing in a field, but may be ingested when they are mixed into harvested forages when they have lost a disagreeable smell or when the possibility of the animal to be selective is limited, as in the case of horsetail or jimson weed.

Table 9.8. Major plant poisonings in the horse (Garnier *et al.*, 1961; Jean-Blain and Grisvard, 1973; Lewis, 2005).

Common name	Toxin and location	Predominant clinical effects
I. Trees, bushes, shrubs		
Black locust (*Robinia pseudoacaccacia*)	toxalbumin robin bark of the tree	digestive and cardiac disorders lethal dose: 150 g of bark
Boxwood (*Buxus sempervirens*)	alkaloids all the parts of the plant	digestive signs. acute intoxication. lethal dose: 750 g of leaves
Common goldenchain tree (*Laburnum anagyroides or vulgare*)	alkaloids: cystisine all the parts	convulsions and dyspnoea, colic, salivation lethal dose of seeds: 200 to 400 g
Mistletoe (*Viscum album*)	viscotoxin, polypeptide the whole plant	digestive disorders, dyspnoea, ataxia lethal
Yew (*Taxus* spp.)	alkaloids (toxins) all the parts except fruits	very frequent, neurologic signs lethal dose: 100 to 500 g of leaves
Wild cherry (*Prunus laurocerasus*)	cyanhydric acid	respiratory disorders , death
Azaleas, Rhododendron (*Rhodendron* spp.)	andromedotoxin	vertigo, ataxia, dyspnoea, digestive disorders, intoxication mainly with ornamental species
Mountain laurel *(Kalmia latifolia)*	unknown, small branches and fruits	gastro-enteritis
Privets (*Ligustrum vulgare*)		
II. Weeds		
Dutchman's pipe (*Aristolochia* spp.)	aristolochic acid (carboxylic acid) the whole plant	paralysis, comatose status, high polyuria (up to 100 l of urine daily) generally non-lethal
Autumn crocus (*Colchicum autumnale*)	alkaloids: colchicine, the whole plant	intoxication with leaves and seeds in spring in autumn, with flowers, hind limb spasms, sweating, diarrhoea, colics, nephritis, lethal dose: few kilos of fresh plants
Foxgloves (*Digitalis purpurea*)	cardiac glycosides all the parts	rare. digestive and urinary signs lethal dose: 140 g of leaves
Bracken fern (*Pteridium aquilinum*)	thiaminase (anti-vitamin B1)	locomotion disorders (treatment with vitamin B1)
Ground ivy (*Glechoma hederacea*)	unknown, the whole plant	cardiac and respiratory symptoms before elevation of core temperature. acute. often lethal
St John's wort (*Hypericum perforatum*)	hypericine, pigment, photosensitizing the whole plant	photodermatitis, erythema, pruritus, cutaneous excoriations, swollen eyelids, only if animal is exposed to sun
Horsetails (*Equisetum* spp.)	alkaloids, thiaminase (anti-vitamin B12) all the parts	with contaminated hay; chronic form: incoordination, weight loss
False hellebore (*Veratrum* spp.)	alkaloids, the whole plant	with contaminated hay. digestive symptoms, muscular tremor, hyper sweating, lethal dose 1 kg of dry leaves

Table 9.8. Continued

Common name	Toxin and location	Predominant clinical effects
III. Cultivated plants		
Sudan grass (*Sorhum sudanense*)	cyanogenic glycosides	acute, lethal intoxication with cyanogenic
Johnson grass (*Sorghum halepense*)	in young plant	glycosides but also hepatic encephalitis signs, hind limb paralysis, abortion
Alsike clover (*Trifolium hybridum*)	unknown	photodermatitis
Crimson clover (*Trifolium incarnatum*)		hepatic syndrome with secondary photosensitization (so-called hepatic encephalitis)
IV. Seed poisonings		
Jimson weed (*Datura* spp.)	alkaloids	with contaminated corn, diarrhoea, anorexia, toxic dose: 0.5% of the feed
Vetch (*Vicia cracca*)	neurotoxic amino acid	paralysis; heavy respiratory disorders (roaring)
Darnel (*Lolium temulentlum*)	alkaloid: temuline very variable content	intoxication with screenings, neurologic symptoms, drunkenness, ataxic locomotion, lethal dose: 3 to 5 kg
Yellow lupine (*Lupinus luteus*)	unknown	jaundice: blood in urine
Corn cockle (*Agrostemma githago*)	saponoside	chronic digestive disorders; weight loss, not very toxic
Vetch (*Vicia sepium*)	neurotoxic amino acids	hepatic encephalitis: neurologic nervous symptoms, digestive symptoms, jaundice
	hepatotoxic substances	photosensitization
V. Fruits – Miscellaneous		
Acorns	tannins	frequent enough; chronic intoxication, serious, often lethal; urinary signs mainly in horse. black and thick urine, death following nephritis
Linseed (*Linum* spp.)	cyanogenic glycosides	acute intoxication, with respiratory signs , meals should not contain more than 350 mg of cyanogenic glycosides per kilo
Castor bean (*Ricinus communis*)	ricin	heavy trembling, sweating, digestive disorders , accidental intoxication by beans in grains, feeds or meal cakes
	only in the seed	lethal dose: 25 to 50 g

Plant poisons can be distributed throughout the whole or nearly whole plant (yew for example) or localised in a specific part of the plant (castor oil phytoxins found only in the seed). Also, concentration of toxins can vary with the seasons or with soil characteristics (yew bush is much more toxic in late winter than during summer).

Some toxins in plants disappear as forages are conserved, either because the toxins are volatile (hemlock) or they undergo chemical modification which changes the properties of the toxins (dimerization of lactones in buttercups).

Nowadays, the most frequent poisonings are observed when horses are out of the stable (hacking, etc.) or when animals are faced with a feed shortage. The horse can ingest poisonous leaves from plants growing around the periphery of the paddocks: yew, boxwood, privet, black locust, mistletoe, and

Goldenchain tree. Horses can equally be poisoned in the pasture by consuming acorns, Dutchman's pipe, and St. John's wort.

Conserved forages can be toxic by contamination: hay with horsetails and false hellebore, silage contaminated with jimson weed. Accidental poisonings can be observed, also after consuming certain screenings of foreign origin contaminated with corn cockle, darnel (*L. temulentum*) and sometimes ergot, or by ingestion of toxic meals normally used as fertiliser (castor bean meal) and accidentally incorporated into feed meals.

Concerning cultivated crops, fatalities of mostly a hepatic nature are a sign of excessive consumption of certain clovers (photodermatitis) like crimson clover or alsike clover. Forage sorghum (Sudan grass, Johnson grass) should not be grazed or offered to horses when the plant is young, because it contains toxins (cyanogenic glycosides). Some legume seeds like darnel, vetch and bitter lupine are dangerous to the horse.

The major plant poisonings with their symptoms and consequences are described in Table 9.8; but additional information can be found from specialised literature and reference books.

9.3.2 Mycotoxins

There are numerous toxic moulds that in theory are capable of causing issues in the horse. But during the last few years, only two cases of mycotoxin poisoning have been diagnosed in France. They are:

- Stachybotryotoxicosis due to the growth of *Stachybotrys atra* on straw that was wet and poorly preserved. This mould secretes a mycotoxin of the type trichothecene satratoxin that causes inflammation of the mouth (stomatitis), runny nose and eyes, conjunctivitis, cracks in the lips and nostrils, fever and death.
- Equine leuco-encephalomalacia (e.g. mouldy corn disease) from the growth of *Fusarium moniliforme* on mouldy corn. Fumonisins secreted by the mould cause neurological effects like anorexia, incoordination and rapid death from a degeneration of the cerebral hemispheres.
- Some moulds like *Aspergillus* or *Alternaria* may induce pulmonary allergies which can cause emphysema in those that handle and distribute the contaminated hays.
- Moulds can also grow on poorly prepared or conserved silage (Chapter 11). The most common moulds are:
  - *Penicillium cyclopium* which only grows in the front of open silos, and produces penicillic acid or patuline which have neurotoxic effects;
  - *Trichoderma viride* can grow in the centre of the silo, and produces trichodermine which has gastro-enterotoxic effects;
  - *Fusarium poae* which secretes poine which produces also gastro-enterotoxicosis;
  - *Fusarium moniliforme* can be present also in maize silages and induces the clinical disorders previously mentioned for whole maize plant or grain.
- Aflatoxin poisonings are fairly rare. *Aspergillus flavus*, *Fusarium sporotrichioides* and *Fusarium equiseti* secrete aflatoxins, trichothecenes and deoxynivalenol, respectively, and are found on contaminated peanut meal, cereal grains and hays that has been badly preserved. Clinical signs are loss of appetite, jaundice and behavioural neurological disorders. Feed regulations have set a maximum of 0.01 μg/kg aflatoxin B_1 tolerated in compound feeds (in France).
- Finally, 'grass sickness' in the grazing horse is caused by a neurotoxic mycotoxin.

9.3.3 Bacterial toxins

Forages or grains contaminated by small animal cadavers (rodents, cats or birds) or by their faeces can cause botulism. This poisoning is from the presence of the neurotoxin from the *Clostridium botulinum* that is contaminating the feeds. It is very serious and can bring about death in 12 to 80 hours after the animal presents symptoms of paralysis of the hindquarters, pharynx and tongue.

9.3.4 Poisonings from feed additives and preservatives

Some antibiotics and ionophores used as growth promoters in the cattle industry (monensin) or as a coccidiostats for poultry (lasalocid, narasin) have been found to be deadly to horses at doses that are normally used in their respective species. Collective poisonings have occurred in France from narasin due to a manufacturing mistake in the making of compound feeds.

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Chapter 10. Pasture

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The horse is an herbivore. Pasture grass is an essential part of the diet during 6 to 10 months of the year depending on the type of animal (mare, yearling, etc.), the breed in question (racing, competitive sport, leisure, or draft), and environmental conditions. Forage may provide 40 to 90% of the animal's total annual nutrient requirements depending on the type and breed of horse.

Permanent grasslands cover high proportion of area under agriculture use (AAU) in Northern, Middle West and East European countries (for example: 30% of the AAU in France (Agreste, 2013). They are found in lowlands (meadows), hills and mountain zones; in regions that are moist or dry. With the exception of the most intensively exploited grasslands reserved for animals with the greatest requirements (i.e. dairy cows), horses range alone or more often in association with, or alternating with, ruminants on permanent pastures where they roam free according to countries. Horses range also sensitive natural areas all over Europe included Southern countries where they contribute to the maintenance and/or the preservation of sensitive natural areas. So far horses are grazing in wide variety of situations.

This chapter describes the management of prairie ecosystems used for pasture, the use of grass by horses, feeding systems, which include pasture grasses, and parasitism associated with eating grass. Also included are recommendations for managing pasture.

10.1 Functioning of the pastured prairie ecosystem

In temperate areas, the sustainability of herbaceous plant communities (grasslands) is linked to repeated defoliation by mowing or grazing, which results in an open environment and prevents colonisation by woody species. Sustainability of grasslands is inseparable from livestock activities. These ecosystems represent a reservoir of plant and animal diversity and provide a number of environmental services, such as erosion control and soil storage of carbon. In an uncertain global context, questions arise as to the capacity of grasslands to adapt to stressors (climate, pests) or to their contributions to the balance of greenhouse gases. At the farm level questions arise concerning the security of foraging systems and the complementarities of grassland types (temporary vs permanent; few vs very diverse species).

In this context and ultimately to best use these ecosystems, it is necessary to have a better understanding of the activities of the various principal biological agents (plants, herbivores, soil micro-organisms) which influence the dynamics of grassland ecosystems. This section focuses on the relationship between management and vegetation dynamics, concentrating on animals, and more particularly horses, in grassland operation.

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10.1.1 The grassland ecosystem, its management and function

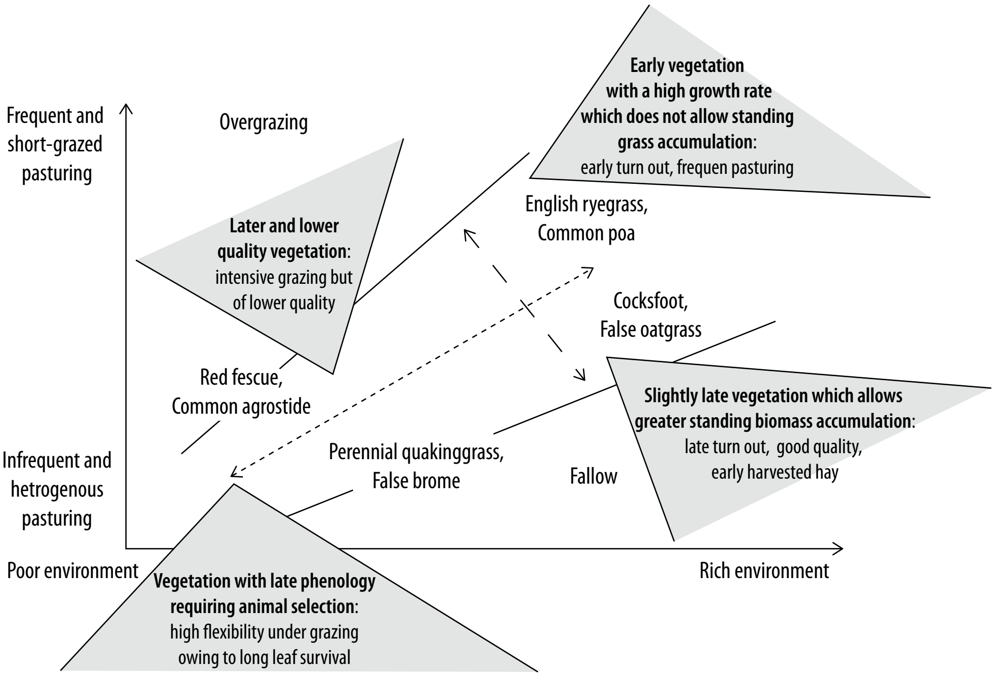
The grazing grassland ecosystem is a complex biological system that integrates air, soil (including micro-decomposers), plant biomass and herbivores. Energy and matter exchanges take place between the various compartments and are analysed across the biogeochemical cycles (water, carbon, nitrogen, phosphorus, etc.). By fixing atmospheric CO_2 absorbing nutrients from soil solutions, plants provide the primary grassland production (PP) of which 40 to 50% is root growth. Herbivores consume a portion of the aerial biomass and expire about 70% of the ingested carbon in the process of obtaining energy necessary for their metabolism. The remainder is returned to the soil in the form of urine and faeces. These excretions contain about 20 to 25% of the nitrogen consumed. The soil, therefore, receives manure rich in nutrients in a form easily mineralisable. In this way animals are important members of the nutrient cycle, especially for nitrogen. The unconsumed above ground plant material (i.e. leaves) and the underground roots senesce and form litter. Part of the carbon, nitrogen and phosphorus from this source accumulates in the soil, while the other part is used by decomposer organisms to produce CO_2 and nutrients that can be assimilated by plants to complete the cycle.

The variety of soil and climatic factors (environment), as well as the diversity of management practices has produced contrasting grassland systems, which differ in their productive capacity and their botanical composition. These differences result from the cumulative effects of cultural practices and the performance of the plant-soil complex. In a given soil and climate context two factors appear as determinants: the availability of mineral elements and the significance of disturbances (Figure 10.1). They determine the botanical composition (species present and their relative proportions) of the community, as well as their performance (biomass production, forage quality, flexibility of use). INRA has demonstrated a high correlation among management, agronomic performance and botanical composition of the grasslands. If light pasture farming (little or no fertilisation, restricted cuttings, low grazing intensity) results in maintaining high species diversity (40 to 70 species per area), intensive practices result in loss and trivialization of the flora.

10.1.2 Understanding mechanisms for predicting changes and performance

In the permanent grasslands of the Massif Central in France, highly variable productivity has been recorded depending on the dominant species in the plant community. In communities dominated by colonial bent grass (*Agrostis tenuis*), red fescue (*Festuca rubra*) and white clover (*Trifolium repens*), annual production is in the order of 3.0 to 4.5 tons of dry matter per ha (DM/ha). Annual production varies between 4.5 and 6.5 tons DM/ha in grasslands where timothy (*Phleum pratense*), Kentucky bluegrass (*Poa pratensis*), oat grass (*Trisetum flavescens*), and white clover (Trifolium repens) predominate. It varies between 6.5 and 9.0 tons DM/ha in areas where cocksfoot (*Dactylis glomerata*), ryegrass (*Lolium perenne*) and rough bluegrass (*Poa trivialis*) predominate. Most of the production (70 to 80%) is in the first growth cycle when soil and climatic factors (temperature, rainfall, day-length, minerals and nitrogen) are most favourable. When one or more of these factors becomes limiting, production is reduced and plant community structure is altered. Growth differences among species during periods of stress illustrate the diverse strategies plants have for obtaining resources. This underlines the importance of having agronomic information on dominant species in order to identify levers which control the function of plant communities.

Such information exists for species traditionally used in temporary grasslands, for example, the production of Perennial ryegrass (*L. perenne*) (Perma variety) varies from 2.5 to 13.0 tons DM/ha/year



The organization of grass plant communities relies upon nutrient availability (richness of environment) and intensity of disturbances (intensity of pasture farming). The continuous lines (—) represent the acceptable limits for sward durability. The broken arrow (- - -) indicates the direction of changes that are driven by pasture farming intensity , the dotted arrow (· · ·) those driven mainly by variation of nutrient availability. Names of species are given for examples.

Figure 10.1. Species strategy and style of grasslands use (Cruz *et al.*, 2002).

depending on nitrogen fertilisation. However, for the majority of grassland species, little is known about the effects of management factors on their production and feeding value. Productivity and nutrition values of 13 species of native grasses from permanent grasslands have been compared by INRA. It has been demonstrated that several native grasses, such as woolly velvet grass (*Holcus lanatus),* tall oats (*Arrhenatherum elatius*) and timothy (*P. pratense*) produce an average annual yield of energy or protein greater than a control ryegrass cultivar. This work also demonstrated that the annual production of digestible energy and protein is highly correlated with several foliar morphological characteristics (called 'traits' in ecology) such as leaf size, dry matter or nitrogen content of the mature leaf blade. The functional approach, which is to group species as a function of their growth patterns, morphology, phenology and composition permits the identification of species that respond similarly to management factors (defoliation) and the level of resources (availability of minerals, water and light).

The concept of a functional group response is an efficient way of taking into account the dynamics of the botanical composition of grasslands. A functional classification of principal grassland grass species has been proposed. Six principal types based on precocity and rate of growth are proposed (Table 10.1).

Table 10.1. Description of the usage value of grasses, their susceptibility to management and associated species (Cruz *et al.*, 2010).

Type	Description	Characteristics	Type of species
A	Fertile environment species, rather small size, phenology: very early with short leaf duration	Grazing early and often	English ryegrass (*Lolium perenne*), Meadow foxtail (*Alopecurus pratensis*), Woolly velvet grass (*Holcus lanatus*)
B	Fertile environment species, tall, phenology: moderately early with leaf life longer than type A	Mow early for good quality. Their ability to accumulate biomass (long leaf life) allows operational flexibility for late mowing if quantity is important	Orchardgrass (*Dactylis glomerata)*, Tall fescue (*Festuca arundicea*), False oatgrass (*Arrhenantherum elatius*)
b	Species preferring a moderately fertile environment but differing from the two previous groups by their late phenology	Subordinate species for mowing for hay or for later summer pastures	Yellow oat grass (*Trisetum flavescens*, mowing for hay), Common bentgrass (*Agrostis capillaris*, pastures with average to good fertility), Timothy (*Phleum pretense*)
a	Short species typical of sparse pastures. These species provide good quality forage in the vegetative stage. They have early phenology	Poorly adapted to mowing practices as they are characterised by low productivity due to the areas in which they are found (often slopes)	Red fescue (*Festuca rubra)*, Crested dog's-tail (*Cynosorus cristatus*), Perennial quakinggrass (*Briza media)*
D	Medium to tall species, very late with long lasting leaves. Grow in poorer quality soils	Typical of waysides and routes with low fertility and use. Species with low forage value	False brome (*Brachypodium pinnatum*), Grooved oat (*Helictotrichon sulcatum)*, Tufted hair-grass (*Deschampsia cespitosas*), Purple moor-grass (*Molinie caeroulea*)

This analytical framework, based on species function, provides an understanding of why an increase in the availability of nutrients tends to increase in the canopy and increases competition for light, thus favouring species capable of investing in vertical structures by making a small number of functional units of large size. All rapid changes in management practices may lead to competition among functional groups, producing the possibility of loss of diversity. Species adapted to underutilisation show convergent traits: for example, less digestible leaves, lower water content, and reduced area per unit of dry matter. These species tend to retain nutrients obtained from slowly decomposing soil litter. This functional approach is essential in understanding on one hand how the diversity of vegetation influences the C-N cycle, thus the persistence of fertility or dynamics of carbon storage in the soil, on the other hand the interaction between plant and animal on the dynamics of the system. On pastures, species groups with contrasting but coexisting functions have been identified within the same plot. The first group corresponds to a competitive species tolerant to grazing, a second of persistent, low growing species capable of avoiding grazing and a third persistent tall species. The first two groups coexist in well pastured areas and the third characteristic of non-defoliated areas. This shows that the structural heterogeneity created by grazing results in significant species diversity having complementary functionality, which, over the plant community is able to guarantee stability and resistance to loss of ground cover (and fulfil their expected functions).

10.1.3 Carbon and nitrogen cycles as a dynamic force in the system.

Nutrient cycles in the ecosystem are closely aligned to management. The stocking rate, which determines the level of consumption of primary production by herbivores, determines the proportion of fertilisation rich in mineral elements (droppings) as compared with that from the poorer source of decaying plants. Fertilisation practices, modifying nutrient availability, increase primary production and stimulate mineralisation of soil organic matter (SOM). Management practices, therefore, modify the balance of components, especially stocking rate or net mineralisation of carbon and nitrogen. Moreover, in permanent pastures, the absence of soil cultivation favours the build-up of SOM.

The diverse plant composition of permanent grasslands results in a certain nitrogen economy over the breadth of the forage-growing system. Leguminous plants are, in fact, almost always present and represent the grassland's principal nitrogen source since they fix, symbiotically, atmospheric nitrogen in their nodules. In the absence of water stress, grasslands contain 15-20% white clover, which can fix in the order of 200 kg of nitrogen per hectare per year. In addition, with high protein content and greater environmental persistence than grasses, legumes forage has a high nutritional value (Chapter 12 and 16). The soil's level of nitrogen fertility and its potential as a source of phosphorus influence legume growth. The excellent capacity to recycle N and P is one of the benefits of the presence of legumes. Similarly, grazing has an influence on legumes dynamics in the sward. Its principal effect is on nitrogen flux via animal droppings as well as in relation to competition among species as to food preferences of the animal. When grazing, it is important to consider the retarded initiation of growth of legumes, which are therefore more susceptible to damage through early grazing. Species complementarities in a diversified sward are regulating factors in the C and N cycles in grasslands. The nitrogen supplied by legumes is transferred via the assimilative species mineralisation. Among the assimilative species highly competitive ones such as ryegrass benefit from a rich supply of nitrogen, while the slower growing species (e.g. fine fescues) can extract nitrogen from lower concentrations. These varied strategies complement each other to ensure the conservation and retention of nutrients in the ecosystem. In addition, the availability of nitrogen in the ecosystem determines the amount of competition among groups and controls the botanical composition of the grassland.

Typical equine behaviour patterns exacerbate the existing plant heterogeneity: depleting P and K in heavily grazed areas and enriching roughs (areas used for droppings). Excessive eating and trampling in the closely grazed surfaces have a positive aspect, especially in areas that are initially overly congested with organic material. It has been shown that in soil samples taken from areas heavily grazed by horses benefit from the decongesting of the catabolic mixture of the SOM and is improved in their ability to fix nitrogen. However, the vegetation will not have the same potential for growth due to the reduced leaf area index and low potassium availability in heavily grazed zones. Such results have recently been obtained in temperate zones located in the mid-western part of France subjected to the oceanic influence (Marais Poitevin).

10.1.4 The animal role in grassland functions

Grazing is a direct and cost-efficient, though often diverse, use of a primary resource. Resource selection by the animal, non-uniform distribution of droppings and trampling, continuously modify spatial structure of the grassland. This results in a large range of habitats, which permits the coexistence of species adapted to various ecological niches and favours plant diversity. During the grazing season plant cover mixtures will change. When grazing pressure is light the animals will focus their grazing activity within a restricted area. Much plant heterogeneity will be present, characterised by the coexistence of heavily grazed areas (reduced quantity, high quality) and areas that are partially or totally neglected (large quantity, low quality). Animal choice depends on the apparent heterogeneity of forage and tends to be reinforced and localised by differential grazing and selection of highest quality plant tissues. The spatial organisation of these areas may be influenced by the placement of points of attraction, such as watering points and sleeping areas. Structure stability is a particular function of range of the study (local vs extensive), grazing intensity and the local plant composition. Horses have the capacity to make use of plants of low to average quality (Section 10.2 of this chapter). They exert heavy localised grazing pressure. Their ability to definitively separate the activities of eating and elimination results in important consequences on plant distribution and function at both field and local levels.

Animal behaviour on pasture (Section 10.2, this chapter) determines the intensity and frequency of localised defoliation and influences, in part, regrowth potential. When the animals return to graze the areas previously eaten, they maintain a plant cover that is immature and highly digestible, which results in a reduced amount of mature forage and increases the availability of soil nitrogen. This positive feedback between pasture and forage quality promotes repeated grazing of previously defoliated areas. The decrease in primary production following defoliation is often less than expected as the vegetation develops compensatory adaptation mechanisms in response to repeated defoliation. This mechanism of 'compensatory growth' is environmental (reducing self-shading), physiological (increase in photosynthetic efficiency, reallocation of growth to aerial parts) or morphogenetic (activation of axillary buds, tillering and clonal development). It increases with the intensity of defoliation and is promoted by a lengthy rest time. It has been shown that sheep graze preferred areas with low frequency but high intensity, rather than the inverse.

At a local level, pasturing influences diversity by reducing competition among plants, but also be selective defoliation, which creates an asymmetric competition for preferred species. At the field level, such modifications of diversity can result from various mechanisms not occurring on a regular basis: animal use of the area, distribution of droppings, and dispersion of seeds contained in faeces. When the specifics of horses at pasture are considered, it is necessary to account for consequences on two levels: the field and the localised area. At the field level, horse behaviour results in marked macro heterogeneity, characterised by areas of heavy grazing and areas of droppings (roughs: refusals areas). It also produces a fertility transfer with depletion of grazed areas and enrichment of roughs. Therefore for given vegetation, the dual behaviour of horses in the use of a field leads to contrasting vegetation dynamics between grazed areas and roughs resulting from the evolutionary strategies of the species (Figure 10.2). At the local level the over-grazed areas will consist of closely cropped vegetation with low amount of biomass left, low primary production of high quality (young leaves. In such areas the vegetation will recover some reserves. The root system will be weak and often impaired because of reduced quantity of nutrients allocate to it, priority being given to aerial foliage for regrowth. Such conditions will select for short species with a prostrate (stoloniferous species) or rosette form, which is advantageous in grazing avoidance. In the roughs the high biomass accumulation is accompanied by reduced quality (increases in structural tissues with high cell wall content). This results in a localised nutrient enrichment, which stimulates primary production and strong competition for light. In these areas there is selection for tall, highly competitive or eutrophic species. The latter have a ruderal, or opportunistic behaviour, which permits them to grow very rapidly in fertile areas and maintain dominance by occupying significant area (bushy growth, large elongated leaves) and spreading rapidly (high seed production and the ability to germinate quickly when conditions are right). This leads to the hypothesis that structural heterogeneity created through pasturing can alter plant community functions and induce divergent persistence in a variety of fields.

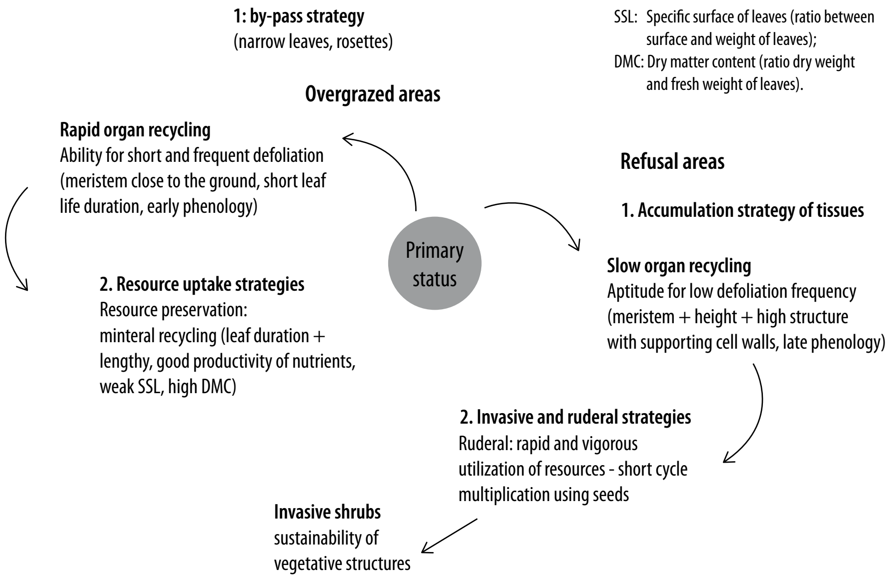


Figure 10.2. Dynamic trajectories and strategy evolution of plant species in overgrazed areas and refusals areas as a result of horse grazing behaviour (Carrère, 2007).

10.1.5 Conclusions

It is accurate to say that pasturing consists of managing the state and productivity of plants to ensure they are aligned with pasture farming objectives. To achieve objectives the manager will use available techniques some of which are starting dates for pasturing, type and duration of grazing, stocking rate, mixture of animals on pasture, alternating harvesting and pasturing from one year to the next, collecting droppings and fertilising as necessary. The effectiveness of these techniques and their aptitude for modifying the performance of the grasslands depends on how they are implemented and the condition of the system in which they are used. Any intervention on behalf of one of these factors represents a system disturbance, which will result in either a return to the original state or a change in status and performance. Precise knowledge in the response of the system to these levers is indispensible to their full utilisation.

In addition, horse pastures provide a management tool in a number of semi-natural environments. Their heterogeneous characteristics, in particular, favour diverse habitats, an important element in maintaining species and plant communities of heritage interest in sensitive locales. In under-exploited areas, horses can be vectors for restarting biological cycles blocked by the accumulation of low quality debris. However, care must be taken that the management system provides an environment with good fertility, which does not allow a marked divergence between grazed areas and roughs. Were a duality to arise it could lead to depletion of grazed areas and eutrophication of roughs.

10.2 Use of pasture resources by horses

The process of grazing arises from a series of decisions taken by herbivores at different time and spatial levels which range from spot grazing to the choice of feeding sites for day long grazing. These decisions respond to relative constraints of plant cover (e.g. forage height, nutritional value) to animal characteristics (e.g. morphologic, physiologic, cognitive, social). Such decisions govern the quantity of forage consumed and the portioning of intake, which in turn determines productive performance and impact on plant cover. Identifying and ranking the factors influencing daily intake and herbivore selectivity is an indispensible prerequisite for animal management that closely match producers' goals.

10.2.1 Forage intake and factors influencing variation

The quantity of nutrients obtained by an herbivore is a function of dry matter intake and ration digestibility. Daily intake is likely to have greater variability than forage digestibility and may be identified analytically as the product of rate of intake and duration of grazing.

10.2.1.1 Rate of intake and daily feeding duration

Rate of intake (IR, g/min) itself is a product of animal bite size and bite frequency. When forage availability is scarce the animal bite size is also reduced. Regardless, thanks to having upper and lower incisors, horses are less constrained by low forage height than other similar sized herbivores (e.g. bovines). When bite size diminishes, bite frequency increases, but this increase will not maintain IR indefinitely. In the majority of herbivores the curve that describes to relationship between IR and the quantity of available resource (referred to as functional response) has an asymptotic form. This result has recently been demonstrated for horses of various sizes (ponies 250 kg, riding horses 600 kg, draft horses 950 kg) fasted for several hours prior to testing (Figure 10.3) then pastured on temporary grassland (biomass, 82 to 513 g DM/m^2, height, 3 to 63 cm, cell wall content, 53 to 68% neutral detergent fibres (NDF)/DM). As with other ruminants, the time required for bite prehension and mastication increased linearly with the quantity obtained with each bite. The result was similar for each type of horse. Taking account of the forage fibre content in the model did not affect the time required for bite prehension (e.g. manipulation). Also horses seemed to be relatively tolerant of forage fibre content within the tested range. In ruminants pastured on spiked forage, stems acted as barriers to bite formation, leading to a reduction in quantity as well as increased manipulation time, resulting in reduced IR.

Horses have a relatively long daily feeding time (on average 15 h/d vs 8 h/d for ruminants). Feeding is organised into meals (usually 3 to 5/d), during which the herd pastures together for several hours. Two principal meals, one early in the morning and another in the evening are evident, a similar pattern to ruminants. Night feeding can represent 20 to 50% of total grazing time for horses. Horses have a relatively rapid digesta transit time due to the absence of a rumen and its role in food particle fragmentation. Studies conducted by INRA, IFCE and CNRS have shown that with a decreased availability of grass, horses have the capability of increasing their daily grazing time to some degree to compensate for the decrease in rate of ingestion. Foals growing on pasture, in a rotational grazing system, on grass cut to 3.5 cm increased their daily grazing time to 19 hours. This mechanism allows the animals to maintain their daily dry matter intake but at an energy cost that has repercussions on their growth (Chapter 1).

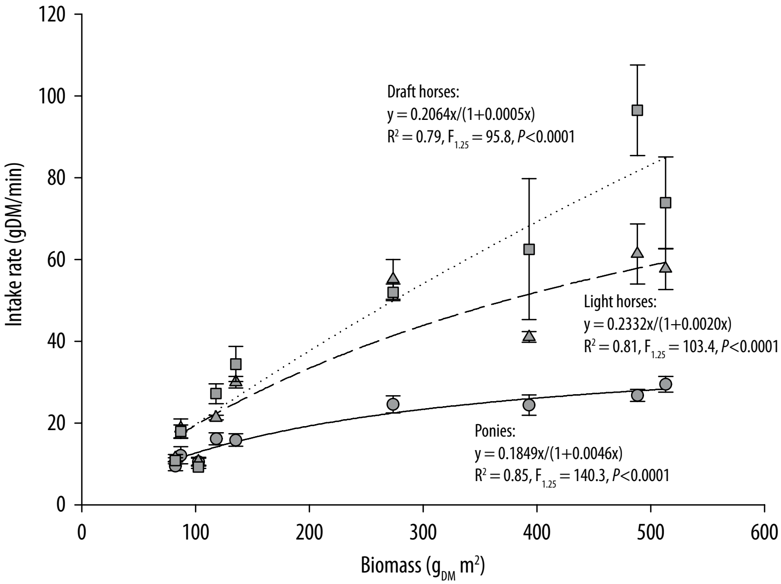


Figure 10.3. Relationship between plant biomass and rate of ingestion (± standard deviation) in ponies (circles), riding horses (triangles) and draft horses (squares) (Fleurance *et al.*, 2009).

10.2.1.2 Daily intake

Herbivore daily feed intake varies primarily in accordance with pasture characteristics, factors which are well documented in ruminants. Level of intake in bovines has been estimated at between 14 and 32 g DM/kg BW/d. Abundant available data has led to predictive models for intake in relation to forage availability and pasture management. In contrast, little work has been conducted on daily intake in horses on pasture and factors influencing variation. Their digestive physiology indicates horses are less constrained than ruminants by the necessity of reducing food particle size (Chapter 1) and are therefore capable of consuming greater quantities of forage than cattle, especially coarse forage. In the humid grasslands of Marais Poitevin (Poitevin marsh, mid-western region of France subjected to the oceanic influence) dry matter intake by growing horses (29 g DM/kg BW/d) was considerably greater than that for young cattle (19 g DM/kg BW/d). The level of intake of digestible dry matter reported in this study was also greater in horses (16 g DM/kg BW/d vs.11 g DM/kg BW/d for cattle). These results support the data obtained at rough feeding work by Duncan *et al.* (1990) over a wide range of forage quality (40 to 70% NDF/DM) fed *ad libitum*. They conclude that digestible dry matter intake is 40% greater in horses. Comparisons regarding meeting requirements for equines or bovines have not been made to date except for trough fed animals. In this instance draft mares have maintained a positive energy balance no matter what their physiological state, even on moderate quality forages (heading or flowering stage), while cows and ewes are not able to meet their requirements for gestation or lactation on the same forages (Figure 10.4) (Chapter 1).

Available results on voluntary intake levels of horses on pasture are limited (Table 10.2). At maintenance draft mares grazing the wet grasslands of the Marais Poitevin marsh and Przewalski horses pasturing on native grassland and reed grass had intakes of 34 and 35 g DM/kg BW/d respectively. These values

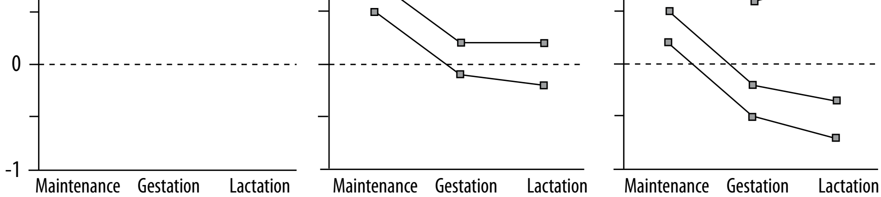


Figure 10.4. Energy balance for mares, cows and ewes according to forage vegetative stage (requirements expressed as multiples of maintenance requirements, forage fed at trough): native grassland, grazing stage (top curve), natural grassland, heading stage (middle curve), Natural grassland, flowering stage (bottom curve) in temperate zone (Thériez *et al.*, 1994).

are much greater than those observed for stabled geldings at maintenance consuming green or dried forage from native grasslands offered *ad libitum* (19 to 23 g DM/kg BW/d). During lactation intake by Camargue mares pasturing on wet native grasslands are quite high (38 g DM/kg BW/d) and greater than those observed when trough fed (31 to 34 g DM/kg BW/d). In growing foals, reported daily intake values on a bodyweight basis are systematically greater for draft breed animals than for those of the light breeds. Similar to trough feeding, intake variation as a function of the foal's age are low when reported on a bodyweight basis. However, describing voluntary intake variation of grazing horses as a function of animal characteristics (e.g. size, physiological state) remains to be determined, while this is relatively well known for trough fed horses (Chapter 1, 3, 5 and 7).

Knowledge of variations in intake levels of animals of similar type with the nature and characteristics of the plant population remains incomplete. Lactating mare housed continuously on wet grasslands in Camargue ingested 34g DM/kg BW/d, compared to 24 g DM/kg BW/d for mares in the same stage of lactation continuously pastured on temporary pastures of ryegrass and white clover in New Zealand. Variability is slightly greater than that seen in trough-fed lactating mares offered, free choice, a different quality, hay based diet (88 to 95%): 28 to 32 g DM/kg BW/d. In contrast, recent work conducted by INRA, IFCE and CNRS has shown that intake by growing horses on pasture is relatively stable if the height and biomass of the vegetation varies within the study range. A decrease in plant biomass from 350 to 230 g DM/m^2 corresponding to plant height reduction from 9.4 to 6.6 cm did not influence intake in foals (on average, 20g DM/kg BW/d) with animal growth being comparable. The young horse also maintained a constant intake level (21 g DM/kg BW/d) on good quality vegetation (49% NDF/DM and 18% CP/DM) between 17 cm (200 g DM/m^2) and 6 cm (71 g DM/m^2) height and biomass, achieving similar growth. It appears that in a similar situation, ruminants of the same size are more limited in their accessibility to forage due to their reduced capability to graze closely and at length. When the forage was allowed to become higher and more mature (80 cm, 830 g DM/

Table 10.2. Dry matter intake by horses at pasture (adapted from Edouard *et al.*, 2009; for a review Collas *et al.*, 2014).

	Bodyweight (kg)	Intake (g DM/kg BW/d)	Pasture	Grassland
Adults at maintenance				
Draft	674	34	Continuous	Native and wetland (Poitevin marsh, France)
Przewalski	279	35	Continuous	Native and reed grass (Austria)
Lactating mares				
Light	560	24	Continuous	Grasses leys (New Zealand)
Light	600	26	Rotating	Grassland, fertilised (Correze, France)
Camargue	372	38	Continuous	Native and wetland (Camargue, France)
Growing horses				
Light (1 year)	350	20	Rotating	Grasses leys (New Zealand)
Light (1 year)	266 -355	12-16	Continuous	Natural ± fertilised (Australia)
Light (1-2 years)	340-480	19-23	Rotating	Grassland fertilised (Corrèze and Normandie, France)
Light (2 years)	477-514	21-24	Rotating	Grassland fertilised (Corrèze, France)
Draft (2-3 years)	719-742	19-33	Rotating	Native and wetland (Poitevin marsh, France)
Draft (2-7 years)	410-850	26-32	Continuous	Native and wetland (Poitevin marsh, France)

m^2, 62% NDF/DM and 7% CP/DM) and the animals were pasturing vegetation of 7, 13, 12 and 80 cm in height using a binary choice, their daily intake remained constant (24 g DM/kg BW/d or 13 g digestible DM/kg BW/d) despite the contrasting choices offered to the animals.

Therefore, even if general laws begin to arise, the diversity of work reveals the lack of comparative studies under controlled conditions, which would permit an understanding of the source of observed intake variations and identification of the horse's ability to meet its requirements in different pasturing situations.

10.2.2 Determinants of feeding choices

10.2.2.1. Influence of the characteristics of grassland vegetation

Horses, unlike ruminants, do not seem to possess detoxification mechanisms for secondary metabolites present in some dicotyledonous plants and preferentially select grasses. Nonetheless they are also quite capable of considerably enlarging their dietary regimen, especially in winter in an outdoor environment (e.g. Camargue) when pasture pressures increase. The palatability of several grasses has been investigated in a series of studies using choice tests. Horses have shown a distinct preference for red fescue (*F. rubra*) and tall fescue (*Festuca arundinacea*), while common ryegrass (*L. perenne*), meadow foxtail (*Alopecurus pratensis*) and timothy (*P. pratense*) were less popular. A preference for the hybrid ryegrass (*Lolium italicum* × *L. perenne*) was also observed. Another important plant defence mechanism against herbivores relates to the presence of non-digestible elements and structural components (plant cell walls), which dilute the fraction of available nutrients and reduce digestibility (Chapter 12). In meadows, horses are known for maintaining themselves by grazing areas of short grass and avoiding areas of tall grass where they concentrate their waste. Such behaviour has long been explained as a strategy for avoiding parasitic infestation but recent work suggests that grazing of short grass areas having high nutritional value by horses may be a means of maximising digestible nutrient intake. Also, when they were given a paired choice situation of vegetation of high quality, growing light breed horses systematically preferred short vegetation of high quality (13.5% CP/DM; 55.5% NDF/DM) to tall, spiked vegetation of lower nutritional value (7.0% CP/DM; 62.0% NDF/DM). Horses fed on short vegetation spent 70% of their feeding time and the intake of digestible protein appeared to be the principal determinant in animal food selection (Figure 10.5).

10.2.2.2 Influence of animal characteristics

Patterns in food choices by horses that may be influenced by the animals' characteristics have only infrequently been addressed. Some authors have shown that lactating donkeys and Shetland ponies have preferentially grazed shorter vegetative grasses than their dry counterparts. Such observations confirm that the intake of digestible protein is a major determinant of food selection by horses. The influence of the animals' social environment has more frequently been the object of study. Social facilitation accelerates the learning process, permitting the acquisition of preference and avoidance knowledge more rapidly than by trial and error. Mature horses are capable of such learning. On pasture, according to some authors, it is even possible to produce a conditioned aversion with the aid of lithium chloride to prevent horses from consuming the toxic plant, locoweed (*Oxytropis sericea*). In contrast, currently it has never been demonstrated that the feeding regime of foals is influenced by

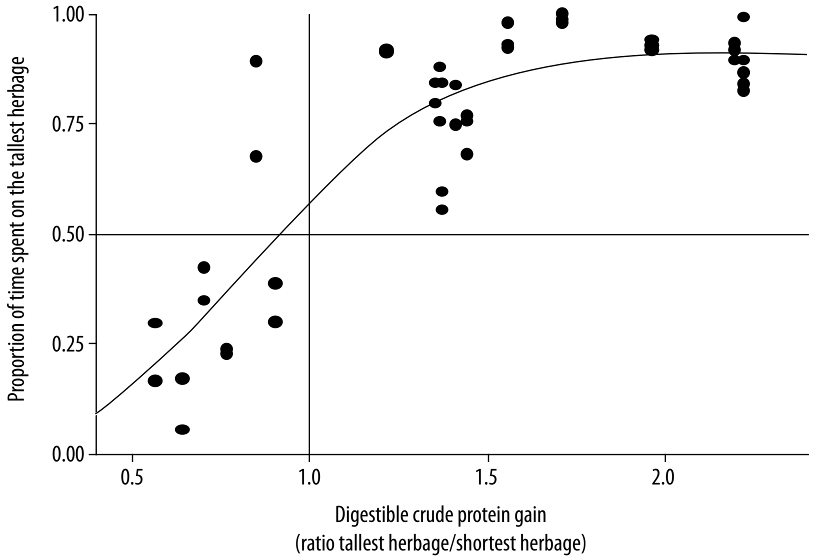


Figure 10.5. Forage selection by horses as a function of the flux of digestible protein intake available from each of plant cover offered in paired choices (Edouard *et al.*, 2010).

their mothers or grazing companions. Agonistic interactions between individuals of the same group will also modify the behaviour and diet of subordinates who may be prevented access to scarce and preferred resources. Pasture studies in the Camargue indicate that mares pasturing in large groups show more agonistic interactions that result in frequent interruptions in grazing sequences than when pasturing in small groups. The initiation of herd movement is in general a process that is distributed among several individuals. In a collective movement, stallions have several times been described as pushing the mares accompanied by their young to encourage them to change feeding sites. It appears that the pushing behaviour may be specific to horses since apart from this, there is no evidence to indicate that horses on pasture have social strategies distinct from those of large ruminants.

10.2.3 Conclusions

Intake regulation and food choices of horses on pasture remain relatively little known in comparison with ruminants. Horses are capable of changing their feeding behaviour (time on pasture, rate of intake, feeding sites) in response to availability and quality of vegetation. Some of the behavioural changes that are described are similar to those seen in ruminants of a similar size: preference for tall vegetation, which permits maximisation of intake flux if the vegetation is high quality, maximisation of protein intake flux and sampling tactics in more restrictive environments. Constraints related to digestive tract functioning are, however, much more limited; intake in horses is less affected by quality of the feed because of the rapid passage of food particles (Chapter 1). Their ability to enhance low quality forage enables horses to contribute effectively to opening of ecosystems as they are able to meet their energy needs while consuming coarse forages. Despite this ability to use mature grass, horses create and maintain areas of grassland that are closely cropped and of high quality, which they are able to exploit preferentially due to their double rows of incisors. In the future it will be important to discover how intake by horses and the selection of their feeding regimen on pasture are influenced by their size and level of requirements.

10.3 Production systems, feeding and forage farming systems

Forage is used in the production cycle of all horses. It is important to identify in temperate zone: under what conditions, modern animal production techniques, and the role of pasture in systems that rely on extensive use of forages.

10.3.1 Production systems and pasture feeding

Systems vary depending upon breed and type of pasture.

10.3.1.1 The lactating mare

Lactating mares of the sport and racing breeds are put on pasture in April during the 1st or 2nd month of lactation, respectively (Chapter 3, Figure 3.10 and 3.11). With leisure and draft breeds this occurs a few days prior to foaling (Chapter 3, Figure 3.12 and 3.13). The pasture season continues for 180 to 240 days depending on breed. Pasture may be prolonged until winter commences for draft and leisure breeds. Average stocking rates for the summer pasture season vary from 1 to 2 mares per hectare depending on breed and type of pasture.

Well managed pasture supply sufficient nutrients to enable lactating mares to meet their nutritional requirements under normal rainfall conditions, except perhaps during summer in drier regions (Chapter 3, Figure 3.12 and 3.15). Mares of racing and sport horse breeds may either maintain optimal body condition (Chapter 3, Figure 3.10 and 3.11) or restore body condition in mares of draft or leisure breeds (Chapter 3, Figure 3.12, 3.13 and 3.15C). Mares of sport, leisure and draft breeds on pasture aftermath restore 56, 85 and 95% of their bodyweight loss respectively, between foaling and drying off. Foals are weaned at the end of summer or early autumn. Supplementation of energy and protein is not required (Chapter 3 and 5) if pasture conditions are optimal: on pasture early and with no summer dry period. Minerals and trace elements supplementation is all that is required to make up for forage deficiencies.

10.3.1.2 The young horse

Young horses are also put to pasture in April at an average age of 12-24 and 36 months depending upon whether they are of the racing, sport or leisure breeds (Chapter 5). Pasture for the sport and leisure breeds lasts for 180 and 240 days respectively. Average stocking rate over a pasture season is 2.6 horses per hectare but with a variation from 1.5 to 3.5 depending on rainfall. Stocking rate also varies considerably during the season if rotational grazing is used due to the rate of growth of grass during the summer (Figure 10.6).

Under normal conditions of forage production and use (on pasture early, without excessive rainfall in spring and an overly dry summer) young horses on rotational grazing undergo either continuous or discontinuous weight gain depending on the growth pattern during the preceding winter. No matter the growth pattern, they will have achieved comparable bodyweight and development at 18-30 and 42 months (Chapter 5, Figure 5.14).

Young horses of sport or leisure breeds, on average, reach 60 to 80% of their total bodyweight, respectively, between weaning and 42 months on fertilised grasslands in Normandy (North-Western region of France under close maritime influence) and Limousin (Central-Western region of France). Supplementation is not required if grass production is normal. The only requirement is for mineral and trace element supplementation to correct for deficiencies in the grass.

10.3.2 Feeding and forage farming systems

10.3.2.1 Principle

Feed requirements of horses during the growth cycle must essentially be satisfied by forages, and in most cases, by pasture grass for economic reasons. However, grass production is extremely variable over the year. This resource must, therefore, be managed and the means found to account for surpluses in spring and deficits in summer and winter (stored forage) by adjusting the areas available to the horses (stocking rates) and by harvesting springtime surpluses.

Daily forage production expressed in kilos of dry matter per hectare varies widely with the season (Figure 10.6). It depends on temperature, water; nutrients available to the roots and the stage of development of aerial plants which make up the grassland (Section 10.1 of this chapter). Producers can modify the choice of species that may respond differently to climatic conditions, level of fertilisation, dates and pasturing management practices, etc., as well as the frequency and harvesting techniques of stored forage. On average, in forage systems used for ruminants, total production of permanent grassland, in lowland areas, is from 5 to 8 tons of dry matter available for animal use.

The feed value of grass also varies throughout the season (Chapter 12). In general, it decreases progressively in grassland species in the development of the vegetative portion from the leaf stage to seed set. At the same vegetative stage nutritional value is greater in the first cut than in all following cuts. However, nutritional value of regrowth decreases less rapidly than that of first growth grass. The

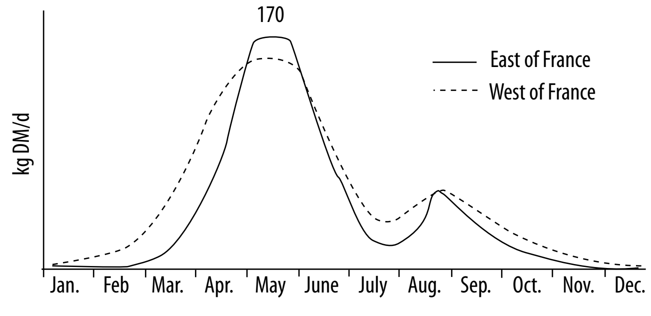


Figure 10.6. Daily production of permanent grassland during the year in in temperate zone (France) (Morhain *et al.*, 2007).

harvest and preservation of forages will result in losses, which will be seen by a decrease in dry matter quantity and nutritional value when compared to primary forage values (Chapter 11).

To maximise forage use when feeding horses, in particular those with high requirements, it must be of high quality and made available free choice. It is, therefore, necessary to recognise that both the availability of this resource will be variable throughout the year due to irregular regrowth and its quality will diminish as the plants age. In consideration of the type of animals fed, the soil and climatic conditions, which together influence animal well-being and soil carrying capacity, the producer has the choice of using the standing grass as either grazed or harvested forage. Standing grass is not the forage left by the animals in the field after a previous grazing but refers to the regrowth after a mechanical harvest or pasturing. Since the mid-eighties the 'French network of reference farms, tomorrow's Cattle Producers' (now called 'Producers Network') have formed a partnership with the Livestock farming Institute (Institut Elevage) at national level and the regional Chambers of Agriculture (Chambres regionales Agriculture). They have proposed recommendations concerning pasture management and entire forage systems adapted to different French regions and different levels of intensification. For each locale, a balanced situation has been defined for the area available to the herd for grazing, the area for harvesting, date of harvest and nitrogen fertilisation. Although adaptation to equines requires changes to be made to stocking rates specific to the species: LU (Livestock Unit: Section 10.3.3 of this chapter), which must then be validated by on site observations (currently being conducted), these recommendations may be useful in the implementation of forage farming systems.

Several simultaneous objectives are envisioned: avoid a lack of grass during the summer when grass growth is slow, store quality forage quantities for the winter feeding period, provide the animals forage of high feeding value for as long a period as possible. A reference example to best achieve these objectives is presented in Tables 10.3 and 10.4. It concerns herds of beef cows in the East of France.

The observed stocking rate varied between 1.0 and 1.5 LU/ha. Up to 1.3 LU/ha, grassland production is sufficient to nourish the animals throughout the year. Above this limit it is necessary to offer additional forage, most often corn silage. In the most extensive situation, without nitrogen fertilisation, stocking rate is about 1 LU/ha. Springtime surplus is harvested in the form of hay cut during June. Considering the late cutting and the slow growth of grass during this period, regrowth can only be pastured after the 10^{th} of July, which necessitates planning for sufficient pasture in the spring (45 ares/LU; 1 are = 100 m^2). During summer, the area must be increased to at least 80 ares/LU. Under these conditions, the growth during May cannot all be consumed and it is impossible to remove droppings. On the other hand, the regrowth (second cutting of grass) is light. The system is thus self-regulating, but with forage of low or average quality from the end of May until mid-July, this will penalise animal performance, particularly the growth of yearlings (calves weaned at 9 months). It is possible to improve hay quality using an early harvest technique which involves pasturing from early April when the soil is firm enough to support the animals and harvesting what is not eaten as hay. The advantage of this technique is to obtain high quality hay while also using the land for pasture during the abundant growth of early spring.

Improvement in forage quality can be accomplished by reducing the grazing surface available to the herd in spring. With moderate fertilisation (70 units of nitrogen per hectare) is possible to reduce pasture area to 35 ares per LU in spring. Under such conditions it is necessary to make available

Table 10.3. Relevance indicators of the forage farming system as a function of stocking rate in temperate zone (France): cattle example (adapted from Institut de l'Elevage and Chambre d'Agriculture: Réseaux Elevage – Farm network 1999).

	Stocking rate (LU/ha)[1]					
	1.0	1.1	1.2	1.3	1.4	1.5
Autonomy (grass stock / total requirements %)	115	110	105	100	90	90
Annual nitrogen fertilisation (nitrogen units/ha)	0	0-40	70	90	90	90
Spring stocking rate (ares/LU)	40-45	40	35	30	30	30
Spring cut/total surface of grassland (%)	>50	>50	>50	>50	>50	>50
Early cut / total surface (%)	0	0	25	25	30	33
Date of cutting			20-25 May	15-20 May	15-20 May	15-20 May
Grass production used (t DM/ha)	5	5.5	6	6.5	6.5	6.5

[1] LU = livestock unit.

Table 10.4. Length of pasture periods and required area as a function of stocking rate in temperate zone (France): cattle example (adapted from Institut de L'Elevage and Chambres d'Agriculture: Réseau d'Elevage – Farm network 1999).

Annual stocking rate (LU/ha)	Required area by pasture period (ares/LU)									
	15/4	1/5	15/5	1/6	15/6	1/7	15/7	1/8	15/8	1/9
1	45						60			80
1.1	40					55			75	
1.2	35					50		70		
1.3	30				45		65			
1.4	30				45		65			
1.5	30				45		65			

to the animals any regrowth from June 20th to avoid a grass deficit as the initial grazing area is not sufficient to meet the needs of the herd. A quarter of the area to be cut must be cut early in the season, at the latest by May 25. To regularly assure a quality product the forage must be made into silage or wrapped bales. Compared to the previous situation the pastured forage is of better quality with less wastage, the immature harvested forage is also of higher nutritional value. The direct result of such practices is shown in growth of the calves, which can be increased by 20%. On the other hand the required mineral fertilisation as well as the early harvesting will increase the cost of the forage. Under such management the global stocking rate is 1.2 LU per hectare and the forage is sufficient to feed the entire herd throughout the year. More intensive management is possible. Such practices are more expensive and are only justified if grass acreage is very limiting.

In all cases, on areas that have not been pastured during the winter, pasture management allows for early grazing as well as harvesting at least half of the area needed for pasture at the end of the season. Some of these systems have been successfully tested by INRA and IFCE under experimental protocols with sport or leisure and draft horses: 15 to 46% of the area has been harvested under conditions found in Normandy (Haras, Le Pin, North-Western lowland region of France under close maritime influence:high rainfalls) and Limousin (Chamberet, Central-Western lowland region of France: moderate rainfalls) with significant annual variation related to climate (Table 10.5). However, grazing systems for horses present peculiarities in the field when compared with those for beef cattle:

On one hand in winter pasture for horses, frequent and abusive use (stocking rate and length of time on pasture), resulted in slow growth and lowering sward production over spring, and must be avoided to assure grassland longevity.

On the other hand, it may be necessary in certain periods to make use of restricted pasture with high nutritional value for animals with lower requirements to avoid certain health problems. (OCD or laminitis; Chapter 2 and 5).

10.3.2.2 Computing grazing and farming management

A computing model named *'RAMI Equine farming, 2015'* has been designed by INRA, IDELE, IRSTEA and IFCE. This model is using knowledge materials on forages production and feeding value (e.g. grass and harvested forages on the farm and/or stud) and recommended feed allowances of the different types of equines during summer and winter periods (Chapters 3 to 8 and Chapters 10, 12 and 16).

Table 10.5. Duration of grazing, stocking rate and harvested forages on pastures located in north-western zone (Normandy region: Le Pin au Haras, high rainfalls) or in Central-Western zone (Limousin region: Chamberet, moderate rainfalls) in temperate zone (France), pastured by young sport horses of different ages (adapted from Trillaud-Geyl and Martin-Rosset, 1990 and 2011).

Age (while on pasture)	1 year (12-18 months)		2 years (24-30 months)	3 years (36-42 months)
Site	Le Pin	Chamberet	Chamberet	Le Pin
Duration (d)	163	169	162	138
Acreage (ha)	11.5	18.5	13.2	11.5
Number of rotations	5	5	4	4
Initial weight of horses (kg)	328	328	440	496
Growth rate of horses (g/d)	596	666	326	540
Average stocking rate over the course of the season (number of animals/ha)	1.9	1.6	1.8	1.9
(Variation during rotations)	(1.2 to 3.0)	(1.2 to 3.0)	(1.3 to 3.9)	(1.4 to 2.3)
Harvested forage TDM/ha	4.2	4.2	4.3	4.1

This software evaluates the balance between available forage production and feed needs of equines bred on the farm or stud. The computer model enables, according to a step-wise approach, the optimisation of grazing and harvesting, e.g. farming management of the stud or farm. In such way the end-users are increasingly educated, getting the skills to implement themselves further the procedure and the tool under the control of an expert-advisor (www.idele.fr or www.ifce.fr).

10.3.3 Evaluation of stocking rate on pasture: LU scale

10.3.3.1 Principle

A stocking rate evaluation system for horses on pasture was developed in 1990 by INRA and the French Livestock farming Institute (Institut de l'Elevage). This system has led to the establishment of a LU scale, which has been tested experimentally between 1990 and 2010 by the French Livestock farming Institute under the French References Techno-economic Network. Results obtained by INRA and IFCE over the years on evaluation of feed values (Chapter 12) and intake quantities of horses on pasture (Section 10.2, this chapter) have validated and updated the LU scale (Table 10.6).

Table 10.6. INRA-IFCE and IDELE horse LU scale (adapted from Martin-Rosset *et al.*, 1990, updated, 2012).

Type of horse	Draft breeds[1,2] 750 kg	Light breeds[2] 550 kg	Ponies[2] 300 kg
Mare alone (dry and pregnant ≤5 months)	0.87 (for 365 d)	0.71 (for 365 d)	0.38 (for 365 d)
Foal weaned at 7 months	0.75 (per head)[3]	0.49 (per head)	0.26 (per head)
Total mare during 1 year + foal weaned at 6 months	1.62	1.20	0.64
Growing animals (females or males)			
7-12 months	0.78 (for 365 d)[3,4]	0.56 (for 365 d)[5]	0.27 (for 365 d)[6]
13-24 months	1.00 (for 365 d)[7]	0.89 (for 365 d)	0.49 (for 365 d)
25-36 months	1.04 (for 365 d)[8]	0.94 (for 365 d)	0.56 (for 365 d)
>36 months	0.98 (for 365 d)[9]	0.78 (for 365 d)	0.41 (for 365 d)
Stallions			
>36 months	1.10	1.00	0.53

[1] For draft horses, use values listed for the mare, alone.
[2] Weight of mature mare.
[3] Foal, not supplemented.
[4] From 7 to 12 months: 0.39 per animal.
[5] From 7 to 12 months: 0.28 per animal.
[6] From7 to 12 months: 0.14 per animal.
[7] Filly, replacement, supplemented: 0.92.
[8] Filly, replacement, supplemented: 0.95.
[9] Filly, replacement, supplemented: 0.79.

The system is essentially based on two criteria: the consumption of coarse forage and the time animals are present on the stud farm. Forage dry matter consumption is, therefore, related to the nutritional requirements of different types of horses (Chapter 3, 4, 5, 7 and 8) and the nutrient value of forages as determined in horses (Chapters 1, 12 and 16). Dry matter consumption corresponds to the intake capacity of horses: that is, the dry matter quantity necessary to meet the requirements of different types of horses of a given size for each breed (Chapter 1). The precise time that the horses have access to pasture corresponds to the effective duration of exposure to the grassland expressed in days in the course of their normal production cycle, which is described for each type of horse in Chapter 3, 4, 5, 7 and 8.

This system was developed along the same principals as those established for beef cattle breeds. Moreover, the LU values were systematically calculated as a relative values in relation to an absolute reference value developed by INRA (1989) for beef cattle: 1 LU = 1 Charolais cow + her calf (48 kg). Specific physiologic and metabolic characteristics of the two herbivorous species were taken into account (Chapter 1). This approach allows the consistence use of the LU on the same farms that produce both horses and cattle.

10.3.3.2 Animal types

Three broad categories of animals are considered for the saddle and draft breeds:
- mare and foal: mare + foal from 0 to 8 months;
- stallion: adult;
- growing animals: males and females from 8 to 48 months.

Reference average adult bodyweights of 750 kg for draft breeds and 550 kg for light horse breeds were established. As well, nutritional requirements for 3 categories of animals for each breed were developed in 2012 (Chapter 3, 4, 5 and 7). The approach has been extended to ponies at the request of owners even though the same level of information is not available (Chapter 8). A reference average adult bodyweight of 300 kg was used. Nutritional requirements are those developed in 2012 (Chapter 8).

10.3.3.3 Reference forage

The average energy value of 0.57 UFC/kg DM represents two green forages native to permanent grasslands pastured in first growth at the full headed and/or flowering stages (Chapter 1 No. FV 0040 and FV 0050, INRA feed tables (Chapter 16) as has been listed for cattle (INRA tables (INRA, 2007), No. FV 0040 and FV 0050, p. 184).

10.3.3.4 Dry matter consumption

The reference quantity of forage dry matter is the amount each type of animal is required to ingest to meet its nutritional requirements. This is uniquely the intake of forage dry matter as the quantity of concentrate feed provided as a supplement for some types of animals is subtracted from the total quantity of dry matter necessary to meet the total nutritional requirements of the animal. The consumption of dry matter established in 2012 to develop this system includes two new features compared to those evaluated in 1990 (Chapter 1 and 12).

In 2012 the energy cost of ingesting forage is taken into account. This results in a reduction in the energy value of forages (Chapter 12), especially that of the reference forage of -8%. As a consequence, the level of consumption is elevated. It has been established that the horse on pasture maintains its daily dry matter consumption per kg bodyweight throughout the season despite the change in chemical composition and structure of the vegetation on maintained pastures, if the stocking rate is optimal (Section 10.2.1 of this chapter).

10.3.3.5 Livestock unit scale

The proposed scale replaces that used on an experimental basis since 1990. It is derived from a nutritional basis specific to horses even though for reasons of consistency and use when horses and cattle are raised within the same farm, the LU calculation is ultimately based on the cattle scale: e.g. LU is the ratio between the quantity of forage dry matter ingested by type of horse to the quantity of forage dry matter ingested by absolute reference value developed by INRA (1989) for beef cattle cow and her calve (Table 10.6).

10.3.4 Conclusions

The possibility of having the periods of high animal requirements coincide with periods when quality grass is available in quantity and, conversely, to be able to eventually restrict animals when plants are less available and/or their feeding value is limited, allows the feeding of horses with diets constituted essentially entirely of forage and pasture grass. In so far, as major errors of management are avoided, animal performance can be maintained with minimal reliance on concentrate feeds and, therefore, considerably reduce feed costs.

However, in many regions a deficit of grass is problematic in summer, especially during dry years, the frequency of which is tending to increase. In order to avoid penalising mare productivity and growth of their foals, a number of producers are advancing the mares' foaling dates even if it means feeding them, in early lactation, with good quality forage and concentrate supplements. Compared with forage systems practiced on cattle farms, equine systems have a much smaller proportion of the grazing area harvested in spring compared to pasture areas, which are very important. This results in the risk of increasing surplus grass and uneaten forage in late spring followed by less rapid regrowth in early summer. It has been demonstrated in cattle farms that such management practices reduce growth in young animals and fattening in their mothers. In addition, winter grazing of horses is common. If it persists too long, it disturbs spring growth in the short term and, long term, it reduces grassland productivity.

At the same levels of fertilisation, the amount of forage consumed by horses is significantly less than that obtained by cattle operations. For the system used for light horse mares with foals (Chapter 3, Figure 3.11), the quantities of forage varies from 4.5 to 6 tons of dry matter per hectare, if the area provided during the summer is from 0.5 to 0.7 hectares per mare. When nitrogen fertiliser is provided at the same level (180 units per hectare), the quantity of forage obtained in the cattle system is at least 7 to 8 tons of dry matter, in a well-managed operation in the Western humid region in France. In the sport horse farms surveyed by the French Livestock farming Institute Institute de l'Elevage to provide techno-economic references information for horses, with low levels of fertilisation, the stocking rate is about one mare per hectare throughout the year. Forage quantity used is about 4.5 tons per mare compared to 5 to 6 tons in cattle operations. The reduced use of forage by horses (lower digestibility: Chapter 1 and 12) partly explains this difference. Their behaviour on pasture, with areas of droppings and areas where they tend to graze very short, handicaps grassland productivity. Inadequate pasture management failing to take note of under grazed forage quantities then leading to their transfer from this period to the next one, and in contrast, periods of significant over grazing because of inadequate resources may produce the same results.

The progress margin in the use of forages, especially grass, by horses are quite important. They rest in the use of an evaluation system of stocking rates on forage areas developed by INRA and the French Livestock farming Institute and on best practices. In the future, innovative strategies of animal management and use of grasslands must be developed to obtain a production response. In addition to the productive function there are new environmental challenges to meet (climate change, erosion of biodiversity) (Chapter 14).

10.4. Pasture management

10.4.1 Animals: choice of grazing system

The producer has a choice between two overall types of pasture systems: rotational or continuous grazing (Figure 10.7).

10.4.1.1 Rotational grazing

Classical rotational grazing consists of dividing the pasture into several plots: a minimum of 3 for fields of average productivity or more for highly productive areas (Figure 10.7E and 10.7F). Horses alone or in association with cattle successively pasture different plots changing more or less frequently depending on plant growth and stocking rate (number of animals/ha) in order to consume the grass in each rotation at its optimum growth stage (Figure 10.8 and 10.9). For this to occur, stocking rate and length of time on the plot must be carefully controlled.

Three distinct stocking rate concepts are visualised:

- 'Instantaneous' stocking rate which is high in early spring (more than 5 horses/ha) in order to make use of the rapid early growth of grass then a reduction in stocking rate in order not to harm grass regrowth.
- An average stocking rate throughout the rotations, which decreases as the pasture season progresses: more than 2 horses/ha during rotations 1 and 2, then 70% of the rotation 1 stocking rate for rotation 3 and 50% for the remaining rotations (Figure 10.8).
- A stocking rate for the total grazing period, which is around 2 horses/ha on good quality grasslands, with a variability of 1.0 to 2.5 depending geographical situation (dry or rainy regions) and the quality of the grassland.

The time on pasture is directly related to the available quantity of grass and the selected stocking rate for each rotation. It increases over the season as the stocking rate decreases (Figure 10.9).

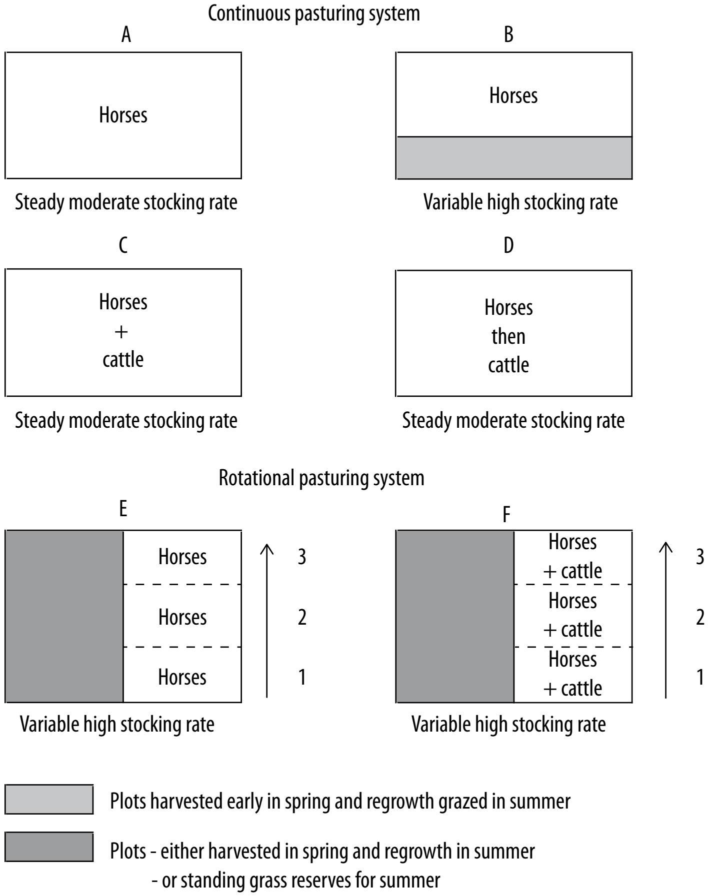


Figure 10.7. Outline of grazing systems.

In practical terms, in the first rotation, grass is pastured for one or two weeks to a height of 10 cm after the heading stage. Regrowth is permitted for 20 to 50 days depending on rotation number. The evaluation of heading appearance in spring is necessary in order to use a rapid rotation of 20 to 25 days. When headings consumption has been halted and regrowth occurs the rotation can be reduced to 30 to 50 days depending on the rate of vegetation regrowth (Figure 10.9). However, only 50 to 75% of the area may be grazed in the first rotation as grass growth can be very rapid in spring. The excess forage can be cut or even better ensiled (wrapped bales). Conversely, in summer grass production decreases considerably, the horses will then graze the areas that were harvested in spring. Difficulties lie in deciding how much of the area to harvest considering annual climatic conditions and the amount of early grassland growth, as well as cutting date, as this will influence the pasturing schedule and the quality of the available grass. Wrapped bales are without doubt the best alternative as this allows quality forage harvest and early regrowth, when compared to harvesting hay. It is preferable to alternate mowing and pasturing of different fields from one year to the next as this gives more control

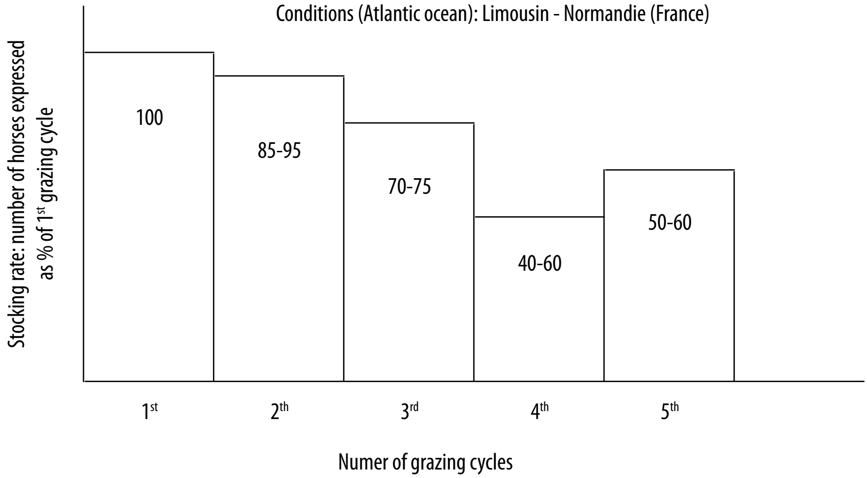


Figure 10.8. Changes in stocking rate throughout the season in a rotational grazing system (adapted from Trillaud-Geyl and Martin-Rosset, 1990, 2011).

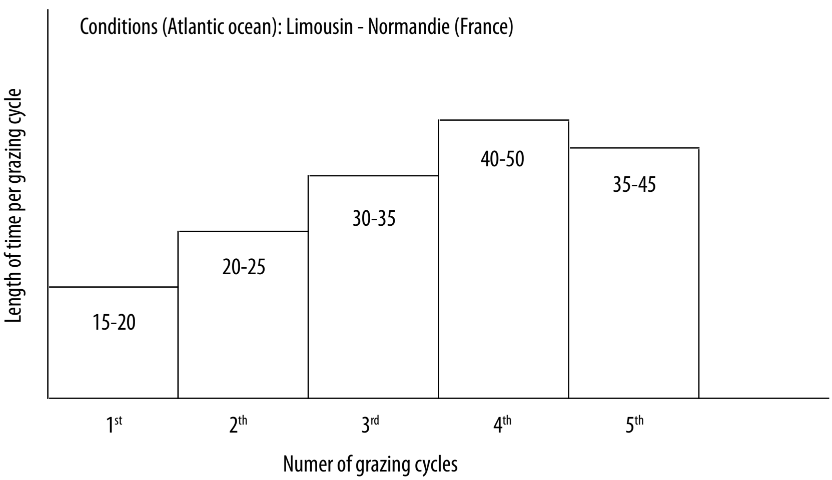


Figure 10.9. Changes in time on total pasture area throughout the season for horses in a rotational grazing system including moderate mineral fertilization(adapted from Trillaud-Geyl and Martin-Rosset, 1990, 2011).

over plant composition and roughs. Roughs should be mowed after the horses are moved at the end of the second rotation. If this is not done roughs can expand rapidly. This system is well adapted to grasslands of coastal zones. The system allows better control of horse feeding behaviour on pasture: areas of grazing and rough areas. It maximises grassland productivity: forage production (associated with manure nitrogen fertilisation and bodyweight gain per hectare).

10.4.1.2 Continuous grazing

Continuous grazing consists of pasturing horses on grassland, most often of a fixed area at a moderate constant stocking rate (Figure 10.7A). Individual animal performance is good but grassland productivity is limited. Controlling the uneaten forage and the management of drought periods is more difficult as the horses will graze the more productive areas. Management and productivity can be improved if part of the area is mowed in spring and the regrowth is pastured in summer, or if the initial area is expanded in summer (Figure 10.7B).

10.4.1.3 Mixed grazing with horses and cattle

Horses can be combined with cattle in a grazing situation simultaneously or separately and successively on the same grasslands in either rotation or continuous systems (Figure 10.7 C,D,F). Such a system will maximise the amount of forage consumed and provide better control of vegetative cover quality due to the complementarities of their feeding behaviour (Section 10.2.2 of this chapter and Chapter 14, Section 14.1).

For example, young draft breed horses of 1 and 2 years of age can be combined on pasture with beef cattle of 1 and 2 years in a rotational system such as that studied by INRA and IFCE in Normandy (Figure 10.7 F). The ratio expressed in percentage of total bodyweight (horses + cattle) should be 30-35% horses and 65-70% cattle on fertilised lowland grasslands to allow adequate growth of both species (Table 10.7). All the forage produced throughout the season is consumed provided climatic conditions are suitable and the total stocking rate is properly adjusted throughout the season without altering the horse: cattle ratio. Such system is increasingly used with dairy cattle: heifers. And young light breed horses could be associated too with beef cattle.

In other pasturing situation horses and cattle (or sheep) may alternate. In breeding farms producing race horses, cattle (beef) or sheep are pastured after first pasturing horses on the fields. Experimental results are not available to allow an objective evaluation of such practices. However, draft horses currently graze, in summer, or at the end of summer or in winter, the forage remaining after the cattle grazing season. In certain situations draft horses clean up the forage remaining at the end of winter before cattle are put on pasture. In all these situations there is no mowing, animal production is maximised and grassland productivity is high if sticking rates and times on pasture are properly managed. Pasturing alternation of young saddle horses and beef cattle is experienced successfully by producers.

10.4.1.4 Animal management principles

An early pasture date is necessary. In temperate zones it is usually in April but this is highly dependent on annual climatic conditions and the soil's carrying capacity especially in spring. Horse imposes considerable pressure on the soil (1.7 kg/cm^2) and they travel greater distances than cattle (3 to 10 km/d, depending on the size of the field). This can lead to a deterioration of the soil (porosity), an adverse change in plant populations and a reduction in forage production more or less permanent. Pasture season is normally from April to November but can vary from 160 to 240 days according to the region and the type of horses involved. The number of rotations may vary from 3 to 5 respectively in the mountain and hilly zones to the lower plains. The 'pasturing' of horses after November in the

Table 10.7. Productivity of natural grasslands fertilised by 2 year-old horses and 1 to 2 year-old beef cattle (adapted from Martin-Rosset and Trillaud-Geyl, 2011; Martin-Rosset *et al.* 1984).

	Normandy region conditions (Atlantic ocean influence)	
	10 horses + 10 cattle	5 horses + 15 cattle
Pasture period – duration	5/4 to 3/10 – 181 d	
Total pasture area[1] (ha)	10.1	10.1
Horses as a percent of total bodyweight	59.9	31.4
Average stocking rate (animals/ha)		
Horses	1.52	0.77
Cattle[2]	1.46	2.20
Daily gain (g/d)		
Horses	579	791
Cattle	793	1,009
Bodyweight gain/ha (kg)		
Horses	155	113
Cattle	242	360
Total	397	473
Harvested forage	nil	nil

[1] 150 units of nitrogen in 3 applications.

[2] Cattle: beef, 1 or 2 years of age.

temperate, coastal zones should be avoided as it depletes vegetation especially by damaging grass tillers and enhances the emergence of less desirable plants, spreading, rosettes, etc., poorly consumed in summer.

Whatever the choice of system and its mode of implementation, the determining factor is the instantaneous and average stocking rate over the course of each rotation along with climatic conditions and nitrogen fertilisation. Measuring the height of the grass using a herbometer tray gives a good indication of available grass quantities before introducing animals into each field. The final element in the decision process is the priority given to individual animal growth or the productivity of the grassland expressed as gain in bodyweight/ha, as a relationship exists between the two parameters and stocking rate (Figure 10.10). At less than optimum individual animal growth is favoured as they can consume grass at will but grassland productivity is limited. At optimum, stocking rate is increased, grassland productivity is higher and animal growth remains high. However, the system is more difficult to manage and it requires greater amounts of nitrogen fertilisation.

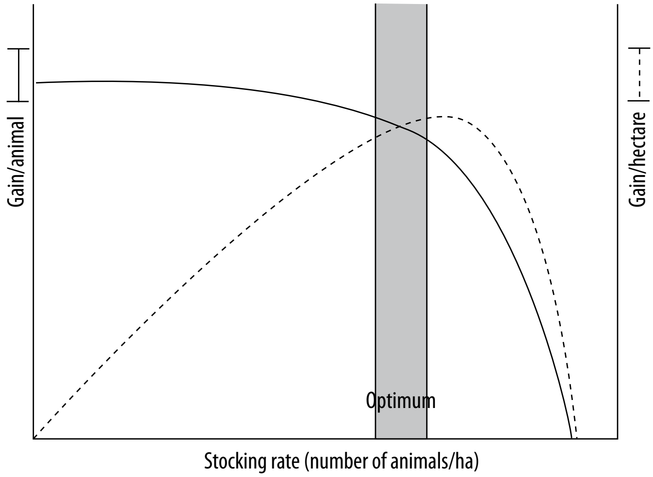


Figure 10.10. Influence of stocking rate on average daily gain and gain in bodyweight per hectare: theoretical model (adapted from Mott, 1960).

10.4.2 The agricultural plan

10.4.2.1 A recognised problem

Grasslands grazed only by horses have heavily grazed areas and roughs. The vegetation in the grazed areas is invaded by rosette plants: daisies, dandelion, large plantain and annual bluegrass. Roughs are colonised by prolific species (woolly houlque, cocksfoot, meadow foxtail, quackgrass, nitrophilous grasses providing a high yield) and other diverse plants (Table 10.8). Soil analysis shows that the roughs are rich in nitrogen and organic matter on one hand and in minerals: especially phosphorus and potassium and to a lesser extent magnesium on the other (Table 10.9). The reason is the concentration of droppings (faeces and urine) by horses on pasture (Chapter 14).

There are few published studies on the condition and development of grasslands pastured by horses compared to those pastured by cattle within the same regional context. In Normandy, the grasslands of the Pays du Merlerault (Orne county) pastured by horses in two study sites are close to regional references with a little more *Poaceae*, a little less *Fabaceae* and more diversity (Table 10.10). These grasslands have evolved slowly since the stocking rate and fertilisation, and other cultural practices are moderate and stable from year to year. In contrast, grasslands can rapidly deteriorate when there is bad horse management and inadequate forage area maintenance (studs in North-Eastern region, France). *Poaceae* only represent 42% and a variety of plants account for close to 50% of which 20% are toxic and undesirable (Table 10.10).

10.4.2.2 Principles for improving grassland management

Fertility of grasslands can be improved by cleaning ditches or installing proper drainage, but only after a thorough, preliminary technical study.

Table 10.8. Species differential between roughs and grazed areas (% abundance) (Leconte, 2012).

Measurement carried out in June	Zone	
	Overgrazed	Roughs
Bentgrass	11.64	2.66
Common dogtail	2.55	0.80
Cocksfoot	0.00	2.50
Tall fescue	0.79	1.69
Woolly houlque	11.41	24.95
Meadow foxtail	5.44	8.95
Wisdon meadows	0.00	2.41
Marsh trefoil	0.08	4.10
White clover	35.22	5.96
Yarrow	0.80	2.42
Carex spp.	1.03	2.57
Thistle	0.08	1.77
Rush spp.	6.44	9.65
Stinging nettle	0.00	0.81
Creeping buttercup	0.16	1.85
Stellar grass	0.00	2.50
Total *Poaceae*	53.6	63.5
Total *Fabaceae*	37.8	14.9
Total other	8.5	21.6

Table 10.9. Mineral content of soil in roughs and grazed areas of stud grasslands in the North-Western region of Normandy, France (Laissus, 1985).[1]

	pH	P_2O_5	K_2O	MgO	CaO
Roughs area	6.28	0.57	0.37	0.26	4.08
Grazed area	6.48	0.30	0.10	0.20	4.08

[1] Fertilisation during the past 3 years: 132 units/ha of P_2O_5, 78 units/ha of K_2O and 1 ton of lime/ha.

A complete soil analysis covering the different areas must be conducted before attempting to improve grasslands. Numerous soil analysis laboratories provide fertiliser recommendations covering several years on the basis of soil samples. Nutritional diagnostics can also be performed along with the soil analysis. This assessment involves estimating nutritional value using a sample of grass. The test results provide a measure of the nutrients available from the soil and amounts contained in the plants, which is a function of a number of parameters related to climate, botanical mix and patterns of use, etc. Such diagnostics can be used on permanent grasslands or on temporary grasslands that have been established for at least 2 years, by which times root systems will have become stable. It cannot

Table 10.10. Botanical composition of the stud grasslands compared to the regional average (% relative presence) in NorthWestern or NorthEastern regions in France (adapted from Leconte, 2012).

Type	Pastures in Norrmandy[1]			Pays du Merlerault Stud[1]		North-eastern[2]
	Pasture	Mowed	Average	National stud[3]	Private studs[4]	Private studs[5]
Years	2002-2010	2002-2010	2002-2010	2010	2008	2004
Number of blocks	341	65	406	11	20	20
English ryegrass	9.83	7.27	9.42	8.40	7.47	8.99
Agrostides sp.	9.47	8.08	9.25	9.17	8.44	6.79
Woolly houlque	7.97	6.46	7.73	7.34	8.96	2.02
Common timothy	8.72	7.49	8.53	10.08	10.38	4.72
Wetland *Poaceae*	6.84	7.37	6.93	14.84	15.56	1.86
Other *Poaceae*	6.19	8.98	6.64	5.75	2.57	7.08
Arid *Poaceae*	5.81	6.99	6.00	2.96	2.46	11.10
Fabaceae	12.17	11.51	12.06	9.98	6.66	8.98
Aromatics and other NA	15.93	22.02	16.91	20.55	17.13	28.82
Toxic and undesirables	17.07	13.83	16.55	10.93	20.36	19.65
Poaceae	54.83	52.64	54.48	58.54	55.84	42.56
Fabaceae	12.17	11.51	12.06	9.98	6.66	8.98
Others	33.00	35.84	33.45	31.48	37.49	48.47

[1] North-Western region in France (Normandy).

[2] North-East region in France (Lorraine).

[3] Mixed pasture, horses – cattle (beef), simultaneously, continuous grazing; stocking rate: 0.6 to 1.1 LU/ha. Fertiliser: 0N – 35P – 45K; mowing the roughs: once/year.

[4] Horses pastured alone, continuous grazing; stocking rate: 0.8 LU/ha; fertiliser: 0N – 30-50P – 50-80K on pasture plus 90K on mowing; mowing of roughs once/year.

[5] Horses pastured alone, continuous grazing; uncontrolled stocking rate from 0.3 to more than 3.0 LU/ha; no fertiliser; no mowing of roughs.

be used for grass-white clover mixtures that contain more than 25% white clover in the spring. The amount of nitrogen fertiliser required depends on the average yield measured in tons of dry matter expected (a function of the animal pressure expressed as LU) corrected for minerals available from soil, contributions from legumes and finally for components of the animals' urine and faeces (Chapter 14).

The effect of mineral fertiliser (N, P, K) in granular form on the mineral composition of grass is known, on average, even though the effect can be variable depending on the retention capacity of the soil (Figure 10.11). Nitrogen fertiliser increases the nitrogen content of grass and a number of elements particularly calcium, magnesium, potassium, sodium and the trace elements. Providing phosphorus increases the plant content of phosphorus as well as manganese and molybdenum. Potassium fertiliser increases potassium content and to a lesser degree calcium and magnesium, but decreases that if sodium. Grassland variability can be corrected by applying composted manure (Chapter 14) and mineral fertiliser only on grazed areas.

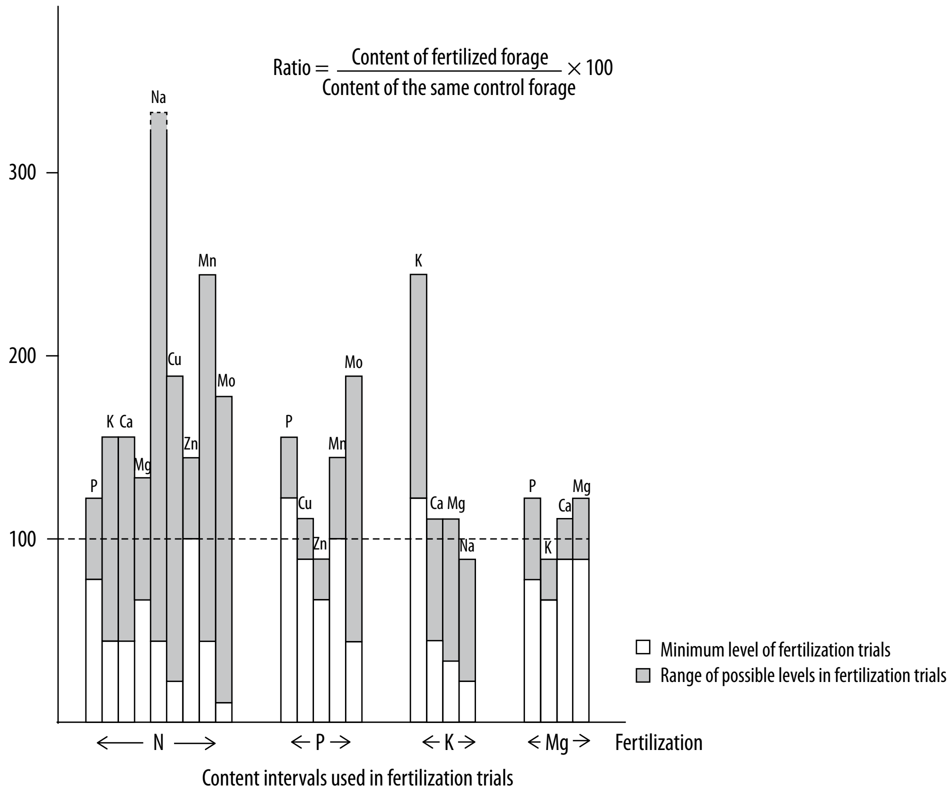


Figure 10.11. Effects of fertilisation on the mineral composition of forage (Perigault, 1975).

Spatial heterogeneity can be reduced through a management plan that mowing the roughs and removing the cut forage if the amount is significant and alternating the mowed-pastured areas from year to year. Harrowing to level the grassland degraded by trampling and to remove dead vegetation is necessary. It is of limited effectiveness if the meadows are not otherwise cleaned and the animal stocking rate is not correctly adjusted. In addition, it has no beneficial effect on mineralisation of the organic matter.

Weeds can be controlled with the use of a cultural plan in conjunction with adequate grazing management. Identifying the causes of weed infestation is the first step and should be a control strategy based on their origin (using the INRA grassland diagnostic method proposed by Leconte, 1991 and popularised by several French professional organizations: GNIS (Interprofessional association for seeds and plants), Livestock farming Institute or ARVALIS (Plants institute). The following should be identified among the causes of infestation:

- overgrazing in summer;
- wet grazing conditions in winter;
- feeding 'contaminated' hay;
- spreading manure contained seeds;
- absence of mowing or mowing too late.

Chemical (herbicide) weed control targeted to problem areas, or control by adapting cultural practices to the life cycle of weeds may be used. Cultural practices include, optimal period of mowing to weaken root reserves, prevent seed development, and tear up roots (dock) (or rhizomes in a pasture renovation situation).

Grassland may be over-seeded with white clover in roughs or English rye grass in grazed areas and in areas of bare soil. Grassland can be reseeded if it is too degraded or more than 20% invaded by undesirable or toxic plants. Diploid English rye grass, fescues, timothy, Kentucky bluegrass, and white clover in moderate amounts may be used in reseeding mixtures (Practical Guide INRA and IFCE; INRA, 2012).

The simple respect of the principles of good management will limit the development of roughs and the presence of weeds in meadows. However, the choice of species and varieties to sow does not only depend on use and expected animal performance, but also on soil and climatic conditions. This is why it is important to contact local information networks (regional Agricultural Offices) concerning grassland management techniques.

Detailed practical recommendations are provided in the Practical Guide (INRA, 2012).

10.4.3 Health plans: parasites

Internal parasites of horses are very diverse, as they include nematodes (round worms), cestodes and trematodes (flat worms), insect larvae (arthropods) and protozoa. On pasture, a major preoccupation concerns infestation by large and small strongyles. In the young, a cestode (*Anoplocephela*) is also encountered. In Europe, 73% of horses of all ages have strongyles (large and small) and 10% have *Anoplocephala* in their digestive tract.

10.4.3.1 Parasite cycles on pasture

Nematodes

The free phase corresponds to the development of eggs present in faeces, shed on pasture, and infective larvae that migrate up grass stems and leaves. This development may take place in 5 to 8 hours under optimal conditions of temperature and humidity.

The parasitic phase is quite different depending on whether it is small (*Cyathostome*) or large strongyles (*Strongylus*). With respect to the later, three species are common and have cycles of migration within the host horse. *Strongylus vulgaris* is an 'arterial' strongyle as its migratory route is through the arteries. Following ingestion, infective larvae enter the caecum and colon and undergo a moult. These new larvae migrate against blood flow to reach the mesenteric arteries where they accumulate and moult to a pre-adult stage. In this stage the larvae migrate via blood vessels to the large intestine where they form nodules in the gastrointestinal mucosa. Pre-adults then leave the nodules and enter the lumen of the large intestine where the mature into adult males and females and reproduce. Six months pass between the ingestion of infective larvae and the excretion of the first eggs in faeces. Ingested *Strongylus edentatus* (hepato-peritoneal strongyles) undertake similar migrations but to the liver via the portal vein and then to the caecum. The time between ingestion and the presence of adult and the excretion of eggs is 9 to 12 months. Migration of *Strongylus equinus* larvae (strongyle hepato-pancreatic) is equally complex. Larvae migrate via the peritoneum to the liver, then to the pancreas from where they then travel to the large intestine. Times from ingestion to the appearance of eggs in faeces are about 9 months. Infective larvae of small strongyles present on grass are ingested and migrate via the digestive tract mucosa. After 2 weeks larvae enter the lumen of the tract and moult into pre-adult form. The interval between ingestion of larvae and excretion of eggs by adults is 2 to 3 months. Finally, a round worm, *Trichostrongylus axei*, which can infest all herbivores, including the horse, has a much shorter cycle of about one month.

Anoplocephales

The tapeworm requires an intermediate host (an oribate mite, present on pastures) to complete its cycle. Development to the infective stage requires 4 months. Ingestion of the mites occurs accidentally while grazing. One to 2 months is needed for the larvae ingested by the horse to reach adult stage after which eggs (or segments) can be found in faeces.

10.4.3.2 Diagnosis of parasites

Laboratory examination of faecal matter

Faecal matter examinations (faecal flotation) enable the counting of parasite eggs. Strongyle eggs are easily differentiated from those of *Anoplocephala*. Eggs of small and large strongyles cannot be identified by direct microscopic examination; this requires culturing faecal material, a process that takes several days. Faecal samples must be taken fresh and the samples should be preserved at 40 °C to prevent the eggs developing into larvae. Samples should be kept cold and delivered to a laboratory as quickly as possible.

Pseudoparasitism and coprophagy

Up to six months of age 85% of foals will practice coprophagy. They will ingest adult horse faeces and if these faeces contain parasites the foals will excrete parasite eggs they have ingested in their own faecal matter. This is pseudoparasitism and faecal flotation exams of the foals will not provide accurate information on infestation by strongyles.

Contamination of fields

Infected material in the fields can be counted. This exam is relatively expensive and only a few laboratories can perform the analysis. Under practical conditions, it is seldom used although this exam does permit identification of the most contaminated fields.

10.4.3.3 Treatments and their proper use

Available chemicals

Products are marketed as name brands or generics. Active components and dose of the therapeutic drugs are given in Table 10.11. It is strongly recommended to never buy unknown generics over the Internet.

Emergency treatment

Although all the anthelmintics are commercially available in France (and likely in other countries) only on veterinary prescription (List 1, art L5144-1 of the CP, in French regulation system), treatment decisions are normally made by horse owners. A treatment schedule has been published in a veterinary review: April (nematodes and *Anoplocephala*), June (nematodes), September (nematodes), and November (nematodes, *Anoplocephala*, and *Gastrophilus*). Repeated treatments cannot be a permanent strategy; in fact strongyle resistance in horses to the drugs is widespread. Treatments must be integrated with good pasture management.

Adjust dosage to weight

Under-dosing because of underestimation of weight is common, even among the sport horses. Bodyweight must be estimated at least with the use of the method and equipment described in Chapter 2, Section 2.2.1. Use of this estimation avoids large errors of under dosing.

Table 10.11. Therapeutic drugs for horses (adapted from Dictionary of veterinary drugs and animal health products sold in France, 2005 and Marchiondo *et al.*, 2006).

Target parasites	Active principle	Dosage per kg bodyweight
Nematodes (small and large strongyles)	thiabendazole	50-100 mg
	febantel	6 mg
	fenbendazole	7.5 mg
	mebendazole	5-10 mg
	oxibendazole	10 mg
	pyrantel	6.6 mg
	piperazine	15 mg
Nematodes and Gasterophiles	febantel and metrifonate	6 mg and 30 mg
	mebendazole and metrifonate	5 mg and 30 mg
	ivermectine	200 µg
	moxidectine	400 µg
Cestodes (*Anoplocephala*)	praziquantel	1 mg
	pyrantel	13.2 mg

Treatments and their ecological impact on insect populations

Treatment with macrocyclic lactones (ivermectin, moxidectine) or certain compounds with insecticide potency (metrifonate) have the most impact on insect populations. This impact can reduce faecal ingredient degradation and their accumulation without recycling. This is one reason for not using only these products but also going back to the benzimidazoles (thiabendazole, fenbendazole, mebendazole and oxibendazole) or pro-benzimidizole (febantel) or the tetrahydropyrimidines (pyrantel).

10.4.3.4 Paddock management in reducing infestation

The majority of recommendations are valid for all herbivores.

Mixed pastures

Pasturing horses in common with cattle or small ruminants decreases internal parasites since horse parasites do not develop in other herbivores. Only one nematode parasite, *T. axei*, can infest all herbivores and is present in about 15% of the horses in France.

Limiting winter use of grasslands

Winter reduces the possibility of parasite eggs developing, but does not completely eliminate it. Moreover larvae infestations already on the pasture persist throughout the winter and retain power to infest for several months. Winter pasture may then be a source of infestation.

Newly seeded pastures are free of parasites

Soil preparation for seeding buries larvae and newly seeded pastures do not constitute a source of infestation. Similarly, grasslands that are harvested in spring for silage, or wrapped bales, or for hay in early summer are future pasture sites that are free of larval infestations.

Reduced stocking rates

High stocking rates increase the probability of infestation for horses. This risk can be changed depending on pasture use by horses (Section 10.4.1 of this chapter).

Separate fields for young horses is wise

Youngsters are more susceptible to parasitic infestation and when they are separated from the mothers it is wise to put them into the least contaminated pastures (newly seeded, mowed, etc.).

10.4.3.5 Chemical management of infested fields

Mechanical actions on the fields (ploughing, harrowing if necessary) probably have an adverse effect on infestation of the fields in so far as strongyle larvae present on the grass or in the soil-grass interface get buried in the soil and become unavailable to the horses. However no experimental evidence is available and these cultural practices should be evaluated *vis-a-vis* the reduction in pasture infestations. Classic NPK fertilizers, superphosphates, urea and ammonium nitrates have no effect on stages of pasture nematode infestations. Spreading calcium cyanamide does not provide control of strongyles when an annual application is applied in March. This product appears to reduce infestations of parasites requiring an intermediate host, as with certain cestodes.

10.4.3.6 Managing and preventing resistance to treatments

Managing the introduction of infected horses

When purchasing horses from other sites it is advantageous to have a period of quarantine (and not just for parasites). The introduction of horse without quarantine appears to an important source of parasites, especially those resistant to drugs. When a new horse arrives it advisable to perform a faecal flotation then follow up with treatment with two types of anthelmintics (benzimidazole and pyrantel or benzimidazole and ivermectin for example), and monitor the success of the treatment (10-15 days later).

Alternating anthelmintics

Modes of action of anthelmintics are very different and it is necessary to alternate different groups of drugs (macrocyclic lactones, benzimidazoles or pyrantel).

Reduce the number of treatments

Selection pressure imposed by treatments is a major factor in the development of resistance to antiparasitic drugs in nematodes. Use of faecal flotation provides a means of evaluating treatment success.

Maintain untreated areas of nematodes on pastures

This recommendation has the objective of limiting the dissemination of resistance when it is already present. When resistance has been clearly evaluated, horses, after treatment should be prevented from having access to pastures contaminated by nematodes since, in this situation, only resistant parasites will be present on the pastures. This will aid in reducing resistance spread. It seems that pasture management is different depending on whether horses are infested or not with resistant nematodes. When the parasites are susceptible 'treat and move' is recommended (to fields as clean as possible). When parasites have resistance 'move and treat' is recommended.

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Chapter 11. Harvest and preservation of forages

Eric Pottier and William Martin-Rosset

The horse is a herbivore. As such forages form the base of its diet. The horse is fed with stored forage during 6 months of the annual cycle of raising different types of horses (Chapter 3, 4, 5, 7 and 8) or throughout the year if the horse is working (Chapter 6). Stored forages make up 30 to 90% of the daily ration depending on the type of horse, condition, physiological stage, breed and the techno-economic objectives. Conserved forages may cover from 25 to 85% of the energy requirements and from 20 to 95% of the protein requirements depending on the type of forage. This is why it is important to have a deep understanding of the methods of forage harvest and conservation and their effects on feeding value and hygienic value.

11.1 Techniques and technology

Harvesting forage is a particularly important stage in the year when engaged in raising herbivores. Regardless of the production system, the feeding of the herds depends to some extent on forages harvested primarily in the spring to feed animals throughout the winter and alleviate periods of low forage production. The repeated droughts, more or less severe, suffered in France since the end of the 1990's have revealed all the challenges of managing forages and the composition of the stock. Harvesting forage represents a considerable investment, initially in terms of necessary work involved but also by the direct costs engendered. A study undertaken in France by the County Federation of CUMA (Centre for the use of agricultural machines) in Vendee county in 2002 has evaluated at about 140 €, 240 €, and 130 € the cost, excluding labour, of harvesting a hectare of grass, respectively, as silage, wrapped round bales or hay. These costs vary somewhat as function of yield and the value of a kilo's worth of forage is going to vary significantly as a function of losses suffered at harvest as well as during storage and distribution. The characteristics of the feed when distributed: nutritional value, presence of toxic compounds, will also have an economic impact at least by way of any necessary corrections to the diet. Technical control of the harvest and storage of forage represents an economic stake. This first part covers, comprehensively, the various possible harvesting methods, their advantages and disadvantages and highlights the important points to take into account to produce quality forage in terms of nutrition and health. Of particular interest is grass, harvested and stored in different forms, which remains by far the most used feed for horses.

11.1.1 Different methods of conserving forage

Three methods of conserving forage are readily recognised. Hay is certainly by far the best known and most commonly used for feeding horses. Silage is also a form that has largely proven itself. Envisaged for grass, it has developed in parallel with corn or sorghum cultivation and more recently for cereals, referred to as straw. Finally, the wrapped bale is a much more recent storage form that has truly seen a boom in France over the last 15 years and which, in form, is between hay and silage and is termed wilted silage. Each of the forms of preservation uses different techniques to insure the production of quality forage, considered here from the standpoint of intake and health.

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11.1.1.1 Hay

This form permits the preservation of quality by lowering the water content of the plant to less than 25%, which prevents the micro-organisms, principally fungi, from growing and multiplying. The principal difficulty with this form of harvesting is to obtain a dry matter (DM) content close to 85% when the fresh forage has a water content of 70-80%. Drying requires 2 to 3 days in optimum conditions to more than a week. Drying speed is a function of climatic conditions, forage characteristics (species, water content, biomass present) as well as the harvesting equipment and how it is used. Hay requires, on average, 4 to 5 days to reach a sufficiently high dry matter content. This period poses a well-known weather risk especially with early mowing. This type of drying also requires a certain number of turnings, which helps in the aeration and drying of the forage. These operations are particularly requested where the quantities of forages in contact with the soil are important.

11.1.1.2 Silage

Silage is forage conserved using a preservation process so called moist processing. Forage is harvested and stored with dry matter contents varying between 15 and 35% for green grass and a little higher for corn. The success of preserving forage with such a high water content depends upon the acidification of the environment by the preferential development of lactic acid bacteria, more particularly of the homolactic group, which allows for the development an anaerobic atmosphere. These transform available soluble sugars into lactic acid. Such acidification must occur quickly in order to limit nutrient losses. According to the schedule developed by INRA (Table 11.1) a quality preservation is characterised by several criteria. For silages with less than 35% DM pH must be equal to or less than 4. At the same time the amount of ammonia nitrogen ($N\text{-}NH_3$) must not be higher than 5-7% of crude protein (total N), the level of acetic acid must be less than 25 g/kg DM and only traces of propionic and butyric acids should be present. The success of the ensiling process lies with two factors, the availability of fermentable sugars and the elimination of all traces of oxygen that can encourage the development of lactic acid bacteria. The content and the availability of soluble sugars in the plant material are important. This varies as a function of forage species and their maturity. Sufficient in rye grass (125 to 150 g of soluble carbohydrate/kg DM), levels are often deficient in natural range land grass (60 to 100 g of soluble carbohydrate/kg DM) and lower yet in cocksfoot (30 to 70 g soluble carbohydrate/kg DM) and alfalfa (40 to 80 g/kg DM). Content is also reduced as the plant matures. In addition to content these sugars must also be readily available to the bacteria. This is why the forage must be finely chopped. It is important to eliminate as much oxygen as possible at the harvest site. The silo should be filled quickly and tightly closed. Compaction, which serves to exclude air, is particularly important for silages harvested with a DM content above 30%, which is the case with corn silage or wilted grass or legume silage and also if the silage is coarsely cut.

11.1.1.3 Wrapped round bales

This is a much more recent technique that was initially developed in the northern countries of Europe where climatic conditions to produce quality forages by drying are more difficult. In the traditional production method round bales are enclosed in stretchable plastic wrap, or using current terminology, wrapped round bales, or cubic bales. The stability of fine-cut silage is assured by the rapid acidification of its medium, but this is not the situation with wrapped round bales since the

Table 11.1. Quality of preserved silage: INRA schedule of physical – chemical characteristics (Dulphy and Demarquilly, 1981).

Classes	Volatiles fatty acids (mmoles/kg DM)	Acetic acid (g/kg DM)	Butyric acid (g/kg DM)	N-NH_3% total N			Soluble N % of total N
				Corn	Lucerne	Other plants	
Excellent	<330	<20	0	<5	<8	<7	<50
Good	330-660	20-40	<5	5-10	8-12	7-10	50-60
Mediocre	660-1000	40-55	>5	10-15	12-15	10-15	60-70
Poor	1000-1,330	55-75	>5	15-20	16-20	15-20	>65
Very poor	>1,330	>75	>5	>20	>20	>20	>75

	% DM	pH	N-NH_3 (% of total N)	Soluble N (% of total N)	Lactic acid (g/kg DM)	Volatiles fatty acids (g/kg DM)	Alcohols (g/kg DM)
Correction for dry matter content			X: NH_3		X	X	X
Preservation quality		X	X			X: butyric acid	
Nitrogen value			X	X			
Ingestibility	X		X	X		X: acetic acid	

The quality of conservation will be evaluated according to plant species using mainly:

- acetic acid and VFA for grasses (rye grass in particular);
- the proportion of N-NH_3 and VFA for the legumes (lucerne, namely).

forage stems are essentially fill length. This has the consequence of reducing the density of the harvested forage, thus retaining more air and limiting the immediate availability of the soluble sugars necessary for acidifying bacteria. Stability of this product is only obtained by harvesting forage that has a sufficiently high dry matter content. pH is not such an important criteria in maintaining quality but the dry matter content is as is shown in Table 11.2. The optimal dry matter content to strive for is in the range of 50 to 60%. Studies conducted at the French Livstock farming Institute show that this range can be obtained relatively quickly, in less than two days (cut in the morning and wrapped in the late afternoon of the next day) if the weather conditions are suitable. The wrapped bale technique has the advantage of using the same equipment to harvest and distribute the hay. There is, however, the problem of disposing of the plastic. If this method reduces the number of aerations it will generate an additional cost and require a specific organising of harvesting sites and additional labour. If the wrapping must be done rapidly the constraints are less than with the ensiling process. It is preferable to do it at the time of baling, but it is possible to delay the wrapping for several hours but not more than 24 assuming the bales are not exposed to bad weather. The average harvesting area is about 3 to 4 ha per day if harvesting on medium sized acreages.

Table 11.2. Effect of dry matter content at harvest on butyric acid contamination (Corrot *et al.*, 1998).

Classes for dry matter content	Soluble nitrogen (%)	Ammonia nitrogen (%)	Acetic acid (g/kg DM)	Propionic and butyric acids (g/kg DM)	Spores/g
<30		12.9	13.5	30.7	69,180
30 to 40	63.4	10.9	10.1	16.2	24,550
40 to 50	47.4	6.9	7.6	6.2	2,270
50 to 60	37.8	6.1	6.2	3.3	470
>60	31.2	3.6	5.3	2.2	90
Standard recommendations	<50	<7	<20	<0.5	100 to 1000

11.1.2 Problems of harvesting and preservation of forages

11.1.2.1 Losses at different stages of harvesting and storage

From the moment a forage is cut, various processes will result in dry matter losses. These losses occur at different points in the harvesting process, first in the field, then in storage and for different reasons.

Losses due to respiratory processes

The first losses are induced by the continuation of respiratory phenomena characteristic of plant material after cutting. The significance of these losses is a function of plant species, the speed of drying of the forage and method of harvesting, and weather (dry or moist). These are highly variable. In the case of dry hay these losses persist until the hay has reached approximately 75% DM at a rate of 1 to 1.5% loss of DM per day. These loses are much lower however if the weather is hot and dry, which allows more rapid drying. Final losses will range from 3 to 10% of the total amount of dry matter harvested. They will be less for forages harvested with a higher moisture content (Figure 11.1). With silage or wrapped bales, the respiratory process will continue for some time after harvest. Anaerobic fermentation, necessary for preservation, will lead to other losses of dry matter as it will continue to proceed for some time. These processes are shortened in wrapped bales since fermentation time is reduced.

Mechanical losses

In the various stages necessary for the harvesting of forage, the losses generated by the harvesting equipment and its use will accumulate. First losses occur at cutting. They are principally dependent upon cutting height, the type of mower and the condition of the vegetation, especially if it is laid down. With grasses a variation of 1 cm in cutting height around the recommended height of 6 to 7 cm may vary the yield by 100 to 200 kg of DM per hectare. Also each handling of the forage as part of the effort to improve drying speed or for preservation will also lead to losses. The dry matter content of the forage during processing and the use of equipment will significantly influence the amount of loss. Finally during the harvest there will be some plant material left on the field.

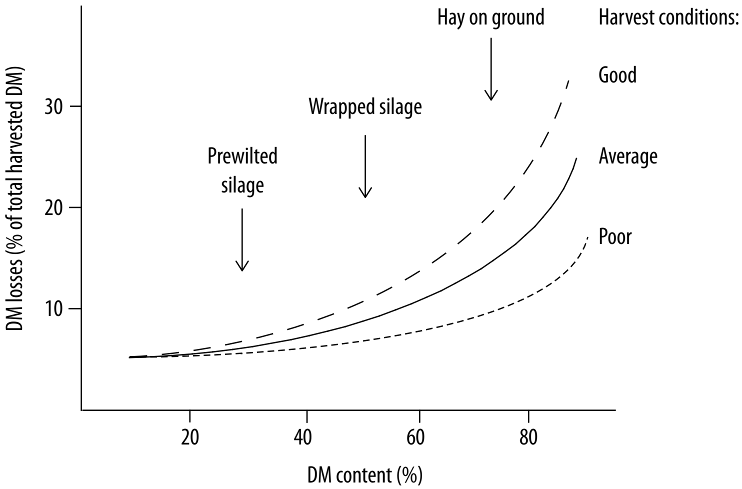

Figure 11.1. Progression of dry matter (DM) losses for the different processes according to harvesting conditions.

Leaching losses

These are losses due to rain on forage during drying. Added to the direct effects of rain on the forage is the increased time spent in contact with the soil and the handling required for aeration for drying. This is primarily as problem for hay and its importance is increased if the drying is well underway and the rain is heavy. Rain increases leaching of the plants soluble constituents, changing the chemical composition, which translates into a reduction in the nutritional value of the harvested forage. Energy and protein values of natural meadow hay harvested at early heading stage during rain is reduced by 0.04 UFC and 3 g MADC/kg DM when compared with forage harvested in good weather. There is a 5% or more reduction in value if the forage is left on the ground too long.

Losses during storage

It is necessary to distinguish among dry hay, moist hay and silage. With traditional dry hay, harvested at 85% DM, storage losses are extremely low if properly stored. According to reports losses vary between 1 and 4%. Lower dry mater values lead to higher losses partly due to heating. In the case of silage, dry matter contents of 30% or less results in juice production, which may leak away. These losses are almost proportional to the DM content of the harvested forage. Finally, the losses due to harvesting and storage are not negligible and may even be significant (Table 11.3). It is estimated that total losses can range from 10% in optimal conditions to about 30%, which may render the resulting forage unusable. Losses are generally higher with legumes (25%) than with grasses harvested dry (10 to 20%). Conversely, under optimal conditions of harvest, total losses in the ensiling process are not much different than for hay. The wrapped bale technique, however, seems to reduce the importance of storage loss.

Table 11.3. Estimation of method of forage harvesting on losses as a percentage of total dry matter (DM) (INRA, 1987).

Losses	Hays, good weather	Wrapped silages at 50% DM	Silage finely chopped -25% DM
In the field	12-18	4- 7	2-3
During conservation	1-2	7-7	10-15
Early distribution	# 0	0-3	3-7
During distribution	2-4	1-2	0-2
Total losses	15-24	9-19	15-27

11.1.2.2 A complexity of micro-organisms

There is a multitude of micro-organisms present at harvest: bacteria, yeast, moulds. Success in storing forage depends on controlling their respective development either by preventing proliferation such as in the case of hay that is at least 85% DM or by encouraging species beneficial to the preservation of forage while restricting other species that could be pathogenic. This technique is essential in the preservation of wet forages.

An abundant and diverse microflora

Forage microflora is particularly diversified. It is possible to distinguish the flora prior to harvest, the flora that is introduced during the harvest and the storage flora. The relative importance of each in storage depends on a number of factors, favourable or not to one or another of these flora. In a simplified manner the micro-organisms can be grouped into 3 categories: lactic acid bacteria, other bacteria, and yeasts and moulds. Lactic acid bacteria are strict anaerobes with a potent ability to acidify. In order to grow they have an immediate need for readily fermentable sugars from which to produce lactic acid which in turn rapidly reduces pH. The second category consists of strictly aerobic bacteria, facultative anaerobes, and the strictly anaerobic butyric acid bacteria. These bacteria are essentially present in the soil as spores and their germination is necessary for development. Finally, moulds are aerobic and yeasts can grow in the presence or absence of oxygen.

Development and variable consequences

The development of these different micro-organisms is always going to result in dry matter losses and a reduction in energy and protein due to the utilisation of sugars and amino acids in the forage. Moulds and yeasts are going to augment these losses by making contaminated forage unpalatable or inedible through the eventual secretion of toxic substances (Chapter 9).

More problematic is the capacity of certain of these micro-organisms, especially of the butyric acid bacteria group, to secrete substances toxic to consuming animals. In the *Listeria* genera the *monocytogenes* species is especially dangerous as it can cause encephalitis and abortion especially in small ruminants eating heavily contaminated forage.

Silages may be inoculated with *Enterobacteria* through spreading organic fertiliser too close to harvesting time. *Enterobacteria* reduce nitrates in the plant to nitrites and nitrogen monoxides or ammonia, which in the dairy cow can result in metabolic problems (alkalosis) and/or reproductive disorders. No problems have as yet been reported in the literature in horses no doubt because the use of silages is not widespread. A pH under 4 and rapid lowering of the pH upon ensiling are the factors limiting their development.

Clostridia contamination of silage occurs due to incorporation of soil at harvest. *Clostridia tyrobutiricum* produce butyric acid and hydrogen from lactates during conservation. Their presence reduces palatability and consumption and a reduction in digestible energy content. At times there is degradation of forage protein with a resultant abnormal level of ammonia production, which may overload the liver's capacity to detoxify ammonia via the endogenous urea cycle. *Clostridium botulinum,* although very infrequent in silage, is very pathogenic especially in the horse as a result of toxins produced by the bacteria (botulism toxins types B, C, D). In the horse these toxins are absorbed directly from the small intestine as opposed to the ruminant where they are largely degraded in the rumen. The proper cutting height, adequate aeration, effective control of moles and voles to prevent the formation of mole hills, spreading organic fertiliser early in the winter and finally a complete sealing of silos will eliminate most risks. The possibility of using effective preservatives has not been studied in horses. Although no such use has been reported in horses, it would need to allow a rapid reduction of pH to less than 4 in silages and a DM content of at least 50% in wrapped round bales as well as good anaerobic conditions to effectively limit the development of *Listeria.*

Moulds are mainly a concern in wrapped round bales with low DM content (<50%) and more rarely in silages if pH is above 5-6. Four factors will aid in their development: presence of oxygen, excessive moisture, significant water activity (w_a coefficient), elevated temperature and available substrates. Four toxins have been implicated in mouldy silage for horses:
- penicillic acid with neurotoxic action;
- trichodermin and poine with gastrotoxic action;
- finally, fumonosins which may produce encephalomalacia.

The risk is, however, limited since most of the toxins produced appear to be unstable in silage that is properly made. In contrast, certain moulds, such as *Aspergillus fumigatus,* have been encountered in heated forages, which may be responsible for mycoses.

The issue of respiratory allergies when feeding hay is an important one in horses and is not negligible in humans, often referred to as farmer's lung, asthma or chronic bronchitis. There are a number of causative agents, moulds (*Alternaria, Mucor, Aspergillus, Penicillium,* etc.) or bacteria.

Category differences in development conditions

The different categories have different development requirements and sensitivities to pH and osmotic pressure. Osmotic pressure is determined by the concentration of plant cell juices and therefore the dry matter content. Also the butyric acid bacteria are very sensitive to low acidity, pH below 4, and more sensitive than lactic acid bacteria to elevated osmotic pressures. Increasing the dry matter content of the forage at harvest improves conservation and limits the development of undesirable micro-organisms (Figure 11.2). This technique is necessary when forages are harvested with long

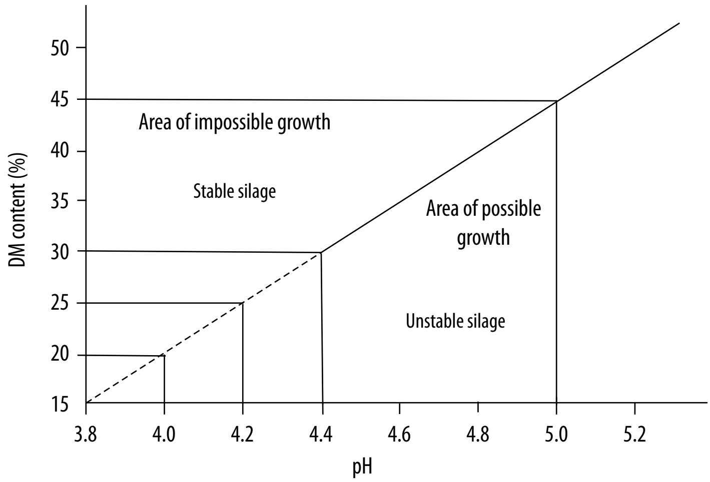

Figure 11.2. Influence of dry matter content on inhibiting the growth of butyric acid bacteria.

stems as is the case with wrapped round bales. Considering *Listeria monocytogenes*, a study conducted by INRA between 1990 and 1992 has shown that in samples from more than 350 forage harvests less than 8% of them were positive. Silages and wrapped round bales were no more contaminated than hay.

11.1.2.3 Adapting to climatic conditions

With the exception of direct cut silage which is used for all the cereals, though less for grasses and still less for legumes, the other types of harvesting, wilted silage, wrapped bales and hay, require a sequence of several days of fine weather, not just without rain but with lots of sunshine. A principal difficulty is to have a period of optimal climatic conditions throughout the entire harvesting sequence. The risk of this not being the situation is greater when the harvesting work is lengthy and takes place early in the year, in spring rather than in summer. Currently wrapped bales are a good alternative for obtaining quality forage. This technique allows early cutting in the spring as well as fall harvests (when weather conditions are often not optimal).

11.1.3 Harvest to storage precautions

This section does not address all the factors influencing harvesting success, only those that can be controlled through technical choices.

11.1.3.1 Ensure rapid drying of forage

Whatever the forage, it is important to ensure that the time on the ground is as short as possible, obviously to limit risk associated with adverse climatic conditions, but also to preserve the best forage quality. The barn drying technique can obviously avoid climatic hazards. However, it is a relatively expensive technique and is only likely to be used where areas to harvest and quantities to dry are large. Nevertheless, these ideal drying conditions, under ventilation and absence of light, will guarantee forage quality in terms of energy, protein and vitamin content high enough to reduce the need for concentrate supplementation. Finally, this method of drying, assuming storage conditions are equally good, limit health risks associated with the growth of bacteria and moulds.

Cutting too low

First of all it is important not to mow too low. With forages that need a certain amount of drying time, cutting height will directly influence drying speed. Firstly, the lower the cut the greater the quantity of forage and the more time will be needed. Secondly, by not cutting too low better air circulation occurs around the forage and drying is accelerated. A cutting height of 6 to 7 cm, or about the width of a hand, is considered a good compromise between the desire for quality and the need for yield (tonnes DM/ha). Mowing should take place when the forage is not wet, and any dew has lifted. There should be no mowing of legumes, such as alfalfa or clover in full sun.

Rake soon after cutting

Drying is rapid in the few hours following cutting and then decreases steadily. To obtain maximum benefit of drying efficiency it is preferable, contrary to routine practice, to rake immediately after cutting. Raking has the benefit of aerating the windrows allowing aeration of the interior forage. This permits earlier work on green forages, which limits loss. This is especially important for legumes such as alfalfa and red clover whose leaves dry much more rapidly than their stems.

Using a conditioning mower

Using a conditioning mower significantly increases forage drying. Such implements are particularly useful for legumes, such as alfalfa, which are characterised by thick stems that are very resistant to drying. The conditioner, which may be a flail or roller, crushes or breaks the stem and thus allows faster drying. In addition to increased drying conditioning it reduces the number of turnings. In all cases the equipment serves to reduce respiration and mechanical losses. Harvesting silage is the exception. It is preferable to not form swaths when cutting, but to allow the forage a maximum of contact with the ground (for a brief period).

Raking early or late in the day

During drying plants dry very unevenly because of density of the forage and its various parts. Leaves rapidly become drier than stems or seed heads and lower leaves faster than higher. Turning the windrows when the upper parts are already relatively dry results in losses that primarily affects leaves and, therefore, the value of the harvested forage. This is particularly important in legumes. Therefore, the introduction of legumes into grasslands primarily composed of grasses should be avoided, which could result in raking a mix too dry. It is always preferable to work with the forage early in the day after the dew has disappeared.

11.1.3.2 Limiting contamination and losses during harvest.

Contamination of forage with soil particles can occur through the cutting, windrowing and turning operations. This problem is most acute in the case of permanent grasslands. It is necessary to check that all areas marked for cutting are clean and free from mounds made by moles or voles that are prevalent in certain areas. The use of a harrow or other such equipment to level the mounds followed by a suitable control program should be implemented.

Don't cut too low

In order to limit contamination of forage at harvest it is best to not cut below 6 to 7 cm especially when making silage or wrapped bales. The collection of forage cut lower than this height essentially mandates the use of a tedder and rake which inevitably leads to the incorporation of soil in the forage. This risk is greater if the soil surface is uneven due to tractor tread marks or footprints.

Aerate at the right time

To reduce mechanical losses do not use the tedder in the late morning or early afternoon. It is always best to perform these tasks in the morning just after the dew has lifted or in the evening when the atmosphere is more humid. Besides the fact that these losses will affect yield they will primarily concern leaf loss and therefore influence the value of the harvested forage. This fact is well understood in the case of important legumes but is also significant for grasses and even more so for clover. The tedding operation, which causes most losses, should not be hurried. It is best to work slowly with a slant tedder.

Keep the fields as clean as possible

Harvesting operations that take place in the field are another important source of contamination especially for silage and somewhat less for wrapped round bales. The field work should be organised to limit as much as possible any introduction of soil into stored feed. This is not easy when silage is made in the field. This is why it is preferable to store silage on concrete or in horizontal silos.

Harvest at the right time

It is very important to obtain the optimal dry matter for each type of crop. To make hay forage should be nearly dry and a relatively accurate DM content should be the target for silage and wrapped bales. For silages minimum DM contents of 25 and 35%, respectively, should be the targets for grass and corn. There is a little more flexibility with wrapped bales. If the desired DM is between 50 and 60%, a crop slight above or below this range will not significantly affect the quality of the feed. The principal problem here may be the development of butyric acid bacteria, which mainly pose problems for dairy farmers.

11.1.3.3 Ensure perfect feed conservation

Whatever the mode of storage and especially if harvesting conditions were not optimal, it is necessary to ensure perfect feed conservation not only to limit unconsumed losses but also to avoid the growth of pathogenic micro-organisms. The success of silage rests to a large degree on the quality of the conservation. It is important to ensure that fermentation reactions do not recommence once the silo is opened, which also means that silage removal for animal feeding must progress sufficiently rapidly at the face. It is recommended that a silage removal rate of 10 to 20 cm per day be maintained.

It is also recommended that the daily requirements of the herd be considered when developing the dimensions for silo construction.

Similar to silage there are rules to follow to ensure proper conservation of wrapped bale haylage. These have been well described (Corrot, 1998):

- in round bales it is necessary to have consistency and high density;
- the plastic wrapping must be high quality and of adequate width;
- when wrapping each turn must produce sufficient coverage of plastic (50%) and at least 4 thicknesses should be in place for drier haylage as stiff stems may perforate the plastic;
- bales should be stored horizontally without stacking and on a flat surface;
- during storage periodic inspection is necessary for holes in the wrapping (birds, cats, etc.) and for the presence of rodents.

Any perforation will lead to a renewal of fermentation. To limit detrimental effects it is recommended to feed these bales as quickly as possible. In winter it is advisable to feed a wrapped round bale in 5 to 6 days.

The use of preservatives for silage and hay is sometimes recommended to better control storage conditions. There is a relatively diverse range of chemicals for the purpose (formic acid, propionic acid salts, lactate products, etc.) which act in different ways, by reducing pH or destroying or inhibiting the activity of undesirable micro-organisms. These products can be effective but their use is difficult and often requires specific equipment for proper incorporation, which limits interest in their use. The potential for using silages with added preservatives for feeding horses has not yet been extensively studied. In all situations their use does not negate the necessity of ensuring that all steps are taken to ensure good forage conservation. Whatever the method of conservation, particularly in the case of high moisture forages, it is illusory to think that conservation will be perfect. Certain parts of the silo or the exterior of wrapped bales may be decomposed and will be best trashed. When such decomposed material makes up much of the bale it is best not to feed it.

11.1.4 Dehydrated forage

Given the cost of energy, it is primarily legumes, especially alfalfa, and whole plant corn that are dehydrated and fed as supplements in the diet. Drying must be carefully conducted with respect to both duration and temperature to prevent development of the Maillard reaction, which produces a combination of proteins and carbohydrates with a resulting decrease in protein digestibility.

11.1.5 Cereal and legumes straws

Small grain cereal straw is available in large quantities for us as bedding and also as feeds for horses. Their harvest is not a particular problem as this is accomplished using the same equipment as for hay, in summer, a more favourable period, when the straw is already dry enough to be baled. Collection of the straw must occur quickly after grain harvest to prevent the straw from becoming wet due to occasional rains or thunderstorms and the subsequent development of moulds. Their nutritive value is low and their supplementation is imperative (Chapter 9, 12 and 16).

The nutritional value of cereal straw can be improved by treatment with sodium hydroxide or anhydrous ammonia (NH_3). The latter treatment is more interesting as it improves not only digestibility but also nitrogen content (Chapter 9 and 16). Anhydrous ammonia is injected by one of the following methods:

- A stack of square bales, covered by a plastic sheet, at a rate of 50 g NH_3/kg of treated straw. The chemical reaction takes 1 to 2 months.
- Into the centre of round bales using a hollow toothed fork (ARMAKO system) at a rate of 3 g NH_3/kg straw. The bales are then covered by polyethylene sheeting.
- A thermal chamber (FMA ovens, SFS, CIL, etc.) at a rate of 30 g NH_3/kg straw. Treatment lasts for 24 hours after heating the straw at 90 °C for 15 hours.

Straw that is treated in this manner is available for feeding after 1 to 3 months depending on the technique and whether the technique was used on 'stacks' or round bales and in summer or fall. The improvement in nutritional value of cereal straw using these methods does not eliminate the need for energy and protein supplementation. Only a portion of the nitrogen incorporated after the ammonia treatment is available for use by horses. Mineral and vitamin supplementation will also be required.

Straws from some grasses (rye grass, etc.) and legumes (peas) grown for seed production do not need to be treated as their chemical composition and nutritional value are better (Chapter 9 and 16). But they must be harvested and stored in good conditions and supplemented just as cereal straws.

11.2 Effect on feeding value

11.2.1 Effects on chemical composition and nutritional value

11.2.1.1 Silages

Only grass silage, whole plant corn silage or range grass silage are fed to horses. Dry matter content of silages ranges from 25 to 35% depending on whether it is direct cut or wilted silage. However, only wilted silage is recommended for horses. Mineral content, crude protein (CP) and crude fibre (CF) contents of silages compared to green forage differ little if they are expressed on a dry matter basis corrected for volatile product lost during the sample drying process. It is, therefore, possible to estimate the chemical composition of the silages from corresponding green forages (Table 11.4) which is very important for predicting the energy and protein values of the silages.

Grass silages have a quantity of soluble protein in the total crude protein significantly greater than that of the corresponding green forage: 45 to 85% compared to 15 to 25% respectively. This quantity of soluble protein has a limiting effect on the true protein value (expressed as MADC) in ensiled forages for horses. This is why the correction factor for DP content of ensiled forage for evaluating the quantity of absorbed amino acids is 0.70 vs 0.90 for green forages in the INRA system of feed protein evaluation for horses (Chapter 12).

Organic matter (OM) digestibility of grass or corn silage is only reduced by 2 to 3 points and less than 2 points, respectively, when compared with fresh forage at the same vegetative state for each type of ensiled forage. The result is that OM digestibility of the silage may be accurately predicted from

Table 11.4. Estimation of the chemical composition of the preserved forage (Y in the equations) from the values obtained from the corresponding green forage (X in the equations) (INRA, 2007).

Methods of conserving	Ash (g/kg DM)[1]	Crude protein (g/kg DM)[1]	Crude fibre (g/kg DM)[1]
Natural rangeland grasses			
Silage			
Pre-wilted	Y = 0.882 X + 21.0	Y = 0.859 X + 26.3	Y = 0.935 X + 31,0
Wilted[2]	Y = 0.479 X + 43.4	Y = 0.926 X + 11.2	Y = 0.757 X + 95,0
Hay			
Force air dried	Y = 0.587 X + 35.0	Y = 0.963 X – 1.0	Y = 0.927 X + 42,5
Ground, good weather	Y = 0.796 X + 14.7	Y = 0.963 X – 1.0	Y = 0.927 X + 42,5
Ground <10 days	Y = 0.839 X + 18.7	Y = 0.963 X – 6.0	Y = 0.852 X + 96,8
Lucerne			
Hay			
Force air dried	Y = 0.809 X + 14.4	Y = 0.472 X + 87.4	Y = 0.670 X + 127
Ground, good weather	Y = 0.809 X + 2.4	Y = 0.472 X + 83.4	Y = 0.670 X + 150
Ground, rain	Y = 0.809 X + 0.4	Y = 0.472 X + 78.4	Y = 0.670 X + 193
Red clover			
Hay			
Force air dried	Y = X – 12	Y = X – 16	Y = X + 38
Ground	Y = X – 3	Y = X – 13	Y = X + 48
Corn			
Silage[3]	Y = X	Y = 0.98 X	Y = 1.05 X

[1] DM = dry matter content of green forage at ensiling (%).

[2] Wilted: wrapped silage.

[3] For corn silages: silages DM (%) = 0.865 DM green forage + 5.96.

that of the fresh forage available at harvest time. The energy value of grass silage made from first cut natural rangeland forage harvested pre-heading is only10% (or -0.07 UFC) less. The energy value of corn silage is the same as that of green forage while the vegetative conditions are good and the dry matter at harvest reach the optimum of 30-35%DM to be fed to horses.

In contrast, true protein content (MADC) of grass silage made from first cut rangeland forage harvested pre-heading is much less (-13% or -10 g MADC/kg DM) than the corresponding fresh forage. However, crude protein digestibility is very similar. The difference is due to the higher proportion of soluble protein in silage, which is poorly metabolised by horses to provide amino acids. Energy and protein values are maximised if wilted silages are harvested at the optimal stage allowed (and recommended) by the harvesting method: first cut or later, pre-heading: e.g. natural rangeland grass: 0.62 UFC/kg DM and 66 g MADC/kg DM (Chapter 16).

11.2.1.2 Wrapped forages

Dry matter content of wrapped round bales varies from 50 to 65%. The ash content of wrapped round bales is less than fresh forage at the same vegetative state while the CF content is higher and there is little difference in CP content.

The digestibility of OM in wrapped round bales is slightly less: 1 to 2 points than the corresponding fresh forage at the same vegetative state, but it is similar to wilted silage harvested at the same vegetative state. The energy value of wrapped round bales is very close to that of silage at first approximation.

Data are not available on the protein value of wrapped round bales. It should be intermediate between fresh forage and hay harvested at the same stage as the proportion of soluble protein in total protein is limited: less than 40% in hays but slightly higher than in fresh forage (15 to 25%) but much less than in silages (40 to 85%). MADC content was 71 g MADC/kg DM for wrapped round bales of rangeland grass first cut harvested pre-heading while it was 73 g and 68 g MADC/kg DM from fresh forage and hay respectively cut at the same vegetative state. The corresponding wilted grass silage has only 59 g MADC/kg DM.

Energy and protein values are maximised if the forage in wrapped round bales is harvested at the optimal stage allowed (and recommended) by harvesting method: first cut, pre-heading: e.g. natural rangeland forage: 0.60 UFC/kg DM and 80 g MADC/kg DM (Chapter 16).

11.2.1.3 Hay

Relative to the corresponding fresh forage the contents of MM and CP on one hand and CF on the other are below and above, respectively. The portion of soluble protein in total protein is a little more elevated: 30 to 45% than those of the corresponding fresh forage (15 to 25%). Changes in chemical composition are greater for hays harvested on the ground in wet conditions than in good weather conditions or in barn dried. Changes are greater for legumes than for grasses, because of leaf fragility and partial loss.

Hay organic matter digestibility is, therefore, reduced by 4 to 6 points compared to corresponding fresh forage (Figure 11.3). Haying thus produces a reduction in energy value of 10% (or -0.07 UFC/kg DM) for rangeland forage harvested at the headed stage under good conditions.

Reduction in DP content of hays is less than 5 to 10% since CP digestibility is reduced 4 to 6 points. The true protein value expressed in MADC is less by 10% (or -8 to -10 g MADC/kg DM) as the content of soluble protein is elevated in comparison with the corresponding fresh forage and a portion of the CP may be less digestible as it is more or less associated with the plant cell wall. In both cases, a significant proportion of CP is poorly utilised by horses.

Energy and protein values of hay are optimal when harvested as first cut, headed out stage, which permits good drying conditions (without significant chance of rain which leaches nutrients and reduces nutritional value) as, for example, natural rangeland forage: 0.55 UFC and 52 g MADC/kg DM (Chapter 16).

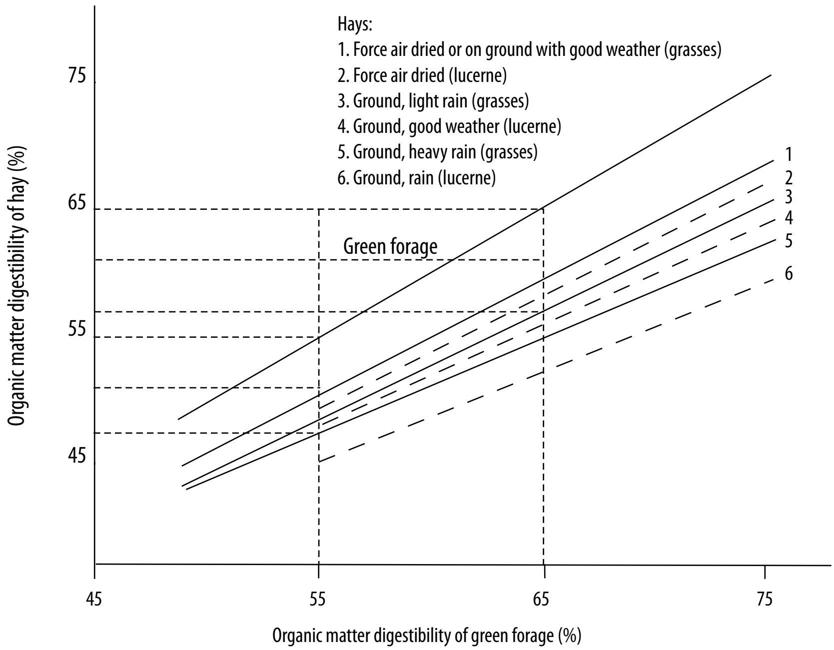

Figure 11.3. Reduction of organic matter digestibility due to haying (adapted in horses from data obtained in ruminants by Demarquilly and Andrieu (1988).

11.2.1.4 Dehydrated forages

Dehydration does not change the chemical composition if drying has been correctly conducted. Energy and protein values are not different from those of a corresponding fresh forage at the same vegetative state. Protein value may be reduced if the drying process is too severe (duration and/or temperature) as it may produce a binding of protein and carbohydrates of the plant called the Maillard reaction, which reduces the digestibility of total protein. This reaction is more significant in legumes.

Energy and protein values of dehydrated alfalfa are 0.62 UFC and 110 g MADC/kg DM for alfalfas of 18-19% CP. They may, however be higher: 0.70 UFC and 146 MADC g/kg DM for alfalfas of 22 to 25% CP which are now available commercially (Chapter 16).

11.2.1.5 Cereal or legume straw

Straws consist mainly of stems and sheaths of mature plants. The plant cell wall, which is rich in lignin represents 80% of DM. Straws are low in protein (25 to 50g/kg DM), in soluble carbohydrates (<10 g/kg DM), in minerals (except potassium) and in vitamins. Straws are, therefore largely indigestible: organic matter digestibility (OMd) 35 to 42% (cereals, peas).

Treatment with alkali or anhydrous ammonia improves digestibility of straw OM by 3 to 12 points depending on the families of cereals or legumes, and the plant species (oats, wheat, etc.), the treatment and the protein and mineral supplementation of the diets. Ammonia treatment elevates total nitrogen matter to 50 to 100 g/kg DM. However, the protein value is not increased because a large part (25 to 30%) of the nitrogen fixed by straw during treatment is excreted in the faeces. Straws treated with ammonia are more palatable than straws treated with sodium hydroxide.

Energy values of native cereal straws or peas vary from 0.29 to 0.36 UFC/kg DM and protein values from 0 to 30 g MADC/kg DM. Straws treated with ammonia have energy values from 0.37 to 0.39 UFC/kg DM. Their protein value is moderately improved due to a significant rise in CP content because of treatment (Chapter 16).

11.2.1.6 In general terms

Harvesting method particularly and conservation to a lesser extent can modify the content of minerals, trace elements and certain vitamins in forages. During harvesting mineral content is reduced as there is a loss of organic matter through respiration, which ceases when the DM content rises to 65%. Losses are more or less important depending on the time taken to reach this threshold (Table 11.5). Prolonged drying of hay on the ground under wet conditions leads to accelerated oxidative destruction of carotene, the precursor of vitamin A (Figure 11.4).

Changes may also come from a reduction in the proportion of leaves and blades in favour of stems. This is particularly true in the case of legumes because of a rough harvest or a prolonged drying time that results in leaf detachment.

During ensiling mineral content decreases due to two contradictory phenomena: a loss of organic matter (by respiration and fermentation) which leads to an increase, on average, of 10% in mineral content and a loss of 5 to 35% of minerals due to leaching of soluble elements (Table 11.6).

Minerals and trace elements contents can be artificially increased by cutting the silage too low or because of the presence of elevated mole hills. In contrast, silages insure a satisfactory conservation of carotene (Figure 11.4). Dehydration has no effect on the major minerals. It also preserves essential carotenoids if done properly (Figure 11.4).

Table 11.5. Possible modifications to the mineral composition due to harvesting (as a percentage of fresh forage) (INRA, 1981).

		Force air dried hay	Hay dried on earth	
			Good weather	Wet weather
Grasses	Ca P Mg	0	0	-10
	Na K	0	0	-30
Legumes	Ca P Mg	-5	-10	-20
	Na K	0	0	-30

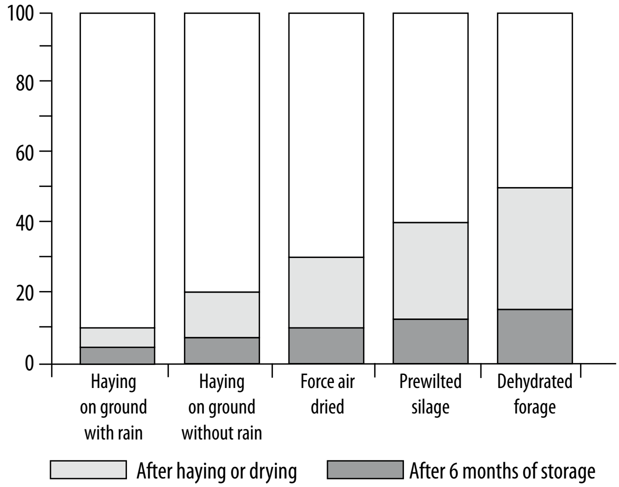

Figure 11.4. Effect of method of forage harvest and conservation on relative availability of carotene compared to initial concentration in fresh forage (INRA, 1988).

Table 11.6. Possible changes in mineral composition due to ensiling (as a percentage of fresh forage) (INRA, 1981).

No loss of DM in juice		Ca P Mg	Na K
		+10	+10
DM % at ensiling	20-23	0	-5
	18	-5	-10
	13	-20	-35

11.2.2 Optimum cutting stages for the harvesting of conserved forages

11.2.2.1 Natural rangeland grasses

During the first vegetative growth nutritional value decreases while the quantity of dry matter produced per hectare increases with the age of the plant. To obtain a harvest of optimum UFC/ha a compromise must be found at the moment of heading (Figure 11.5). If the forages are harvested at the pre-heading stage the quantity of UFC/ha is maximised because the energy content and DM production per ha are high. These forages are fed to animals that have a high demand: mares and yearling foals (first winter after weaning). Regrowth will be early and extensive. If harvesting is delayed to obtain forages for horse with more limited nutritional requirements (2 to 3 year old horses), DM quantities per ha will be higher and the energy content will again be satisfactory if the heading out stage is not complete. In this situation regrowth will be retarded and reduced. Harvesting of second growth forage should take place around 6 weeks (regrowth of stems) to 8 weeks (regrowth of leaves).

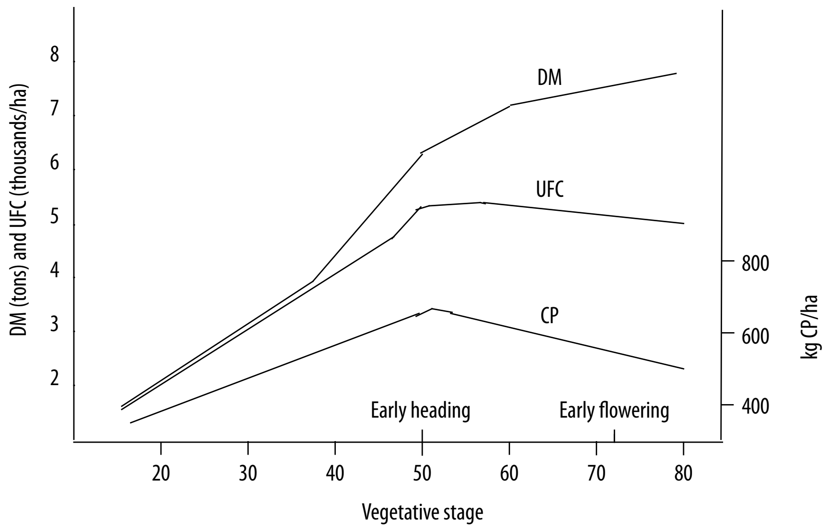

Figure 11.5. First cycle vegetative growth of Italian rye grass and the quantities of DM, UFC and CP per hectare (adapted in horses from data obtained in ruminants by Demarquilly and Andrieu, 1988).

11.2.2.2 Corn

Digestibility of whole plant corn is almost constant because the growth of the ear, which has a high digestibility compensates for the reduction in digestibility of the remainder of the plant (Table 11.7).

The optimum stage for harvesting is about 2 months after flowering, when the grain has reached the flint stage (30 to 35% DM). Production of UFC and DM/ha is at a maximum and DM is ideal for conservation as silage.

Table 11.7. Average morphologic composition of the entire corn plant from flowering to grain dent stage (physiological maturity) which takes place 60 to 70 days after florescence (adapted from INRA, 1988).

Vegetative stages	Start of flowering	Milk stage	Dough stage	Dent stage
Dry matter content of the plant (%)	14-16	21-24	25-29	32-35
Dry matter in different parts of the plant (%)				
Leaves	20-25	15-18	12-15	10-12
Stems + seeds	50-55	35-40	25-30	20-25
Ears with husks	20-25	45-50	55-60	60-70
Grain	0	18-23	35-50	45-55

11.2.3 Stored forage effects on ingestibility

Hays from natural rangelands or from grasses and legumes properly harvested and stored are as well consumed as the corresponding fresh forages: 1.7 to 2.3 kg DM/100 kg bodyweight (Table 11.8).

Well-made silages from wilted rangeland grasses have slightly lower consumption rates than corresponding fresh forages: 1.2 to 1.8 kg DM/100 kg bodyweight, especially if the DM content is limited: 25 to 35% DM. In contrast wilted silage in wrapped round bales has better consumption and the rate of consumption increases with DM content: 2.2 to 2.6 kg DM/100 kg bodyweight. Corn silage is more readily consumed, 0.9 to 2.0 kg DM/100 kg bodyweight, if DM content is higher, 25 and 35% respectively. Dehydrated forages are normally fed in limited quantities. There is no reason for dehydrated forage to be a limiting factor if properly prepared and dehydrated. Consumption of cereal straw is moderate: 1.2 to 1.5 kg DM/100 kg bodyweight. These quantities can certainly be reduced if the straw is in the field too long and is mouldy and dirty.

Table 11.8. Intakes of the principal forages by horses.[1]

Feedstuffs	Dry matter intake (kg DM/100 kg liveweight)[2]
Green natural rangeland grasses	1.8-2.1
Hay of natural rangeland grasses and *Graminea*	1.7-2.1
Legumes hays	2.1-2.3
Cereal Straws	1.2-1.5
Well preserved maize silage	
25% DM[3]	0.9-1.2
30% DM	1.2-2.0
Well preserved grass silages (natural rangeland grasses)	
25% DM	1.2-1.5
35% DM	1.5-1.8
Wrapped grass silage (natural rangeland grasses, *Graminea*)	
45% DM	2.2-2.4
60% DM	2.4-2.6

[1] Maximal amount of dry matter intake when horses are fed forage based-diet *ad libitum*.

[2] The range of intake account for the individual variation between animals according the quality of forage.

[3] DM = dry matter.

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References quoted through the text are only listed; for other references which are supporting the chapter, see 'Further reading'.

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Chapter 12. Nutritive value of feeds

William Martin-Rosset

The nutritive value of feeds in the INRA systems includes two fundamental concepts: the nutritive value and their ability to be ingested, so called ingestibility. Energy and protein values are the main criterion of the nutritive value of feeds. They vary extensively with the type of feeds, forages or concentrates (ingredients or compound feeds), the stage at harvest, conditions of harvest and preservation, etc., and more generally with the chemical composition. In-depth knowledge of these values is of great concern either to rationally feed the horse according to their nutrient requirements and their intake capacity or to choose feeds that are the most relevant in the economical context.

The energy value is mainly related to the digestibility of organic matter (OMd). This represents the fraction of organic matter (OM), which disappears in the digestive tract of the animal. The protein value of feeds depends on the digestible crude protein content as well. Both values should be evaluated and expressed using a relevant system established for horses, the UFC system for net energy and the MADC system for the amount of amino acids.

In practical situations the nutritive value of all feeds that are available for diet formulation, cannot be measured, but can be estimated using chemical or physical characteristics of feeds. Using digestibility data obtained only with horses at INRA in France and abroad, and thanks to the extended data on the variation of chemical composition of two large selections of feeds determined either for forages by INRA (1988-2007) and for concentrates by INRA and AFZ (2002-2004), the INRA equine group proposes tables of the chemical composition and nutritive value of feeds (Chapter 16) and relationships to predict digestibility and nutritive values from the chemical composition.

The aims of this chapter are subsequently to explain how the nutritive value of feeds varies with chemical composition, then to evaluate and finally to predict the nutritive value, and to design the ingestibility of the main categories of forages fed to horses.

12.1 Energy and protein values

Nutritive value is characterised by the energy and amino acid contents of feeds. Energy and protein values are related to the chemical composition of feeds, the digestibility of OM for energy or the digestibility of crude protein for protein and the respective systems used for their evaluation.

12.1.1 Principal organic components

Feeds dedicated to horses are exclusively of plant origin. They consist of water and dry matter (DM). Minerals and OM are the two main components of DM. Organic matter is made up of carbohydrates, lipids and crude protein. These components are located either in the cell wall or in the intracellular content (cytoplasm) of plants (Figure 12.1).

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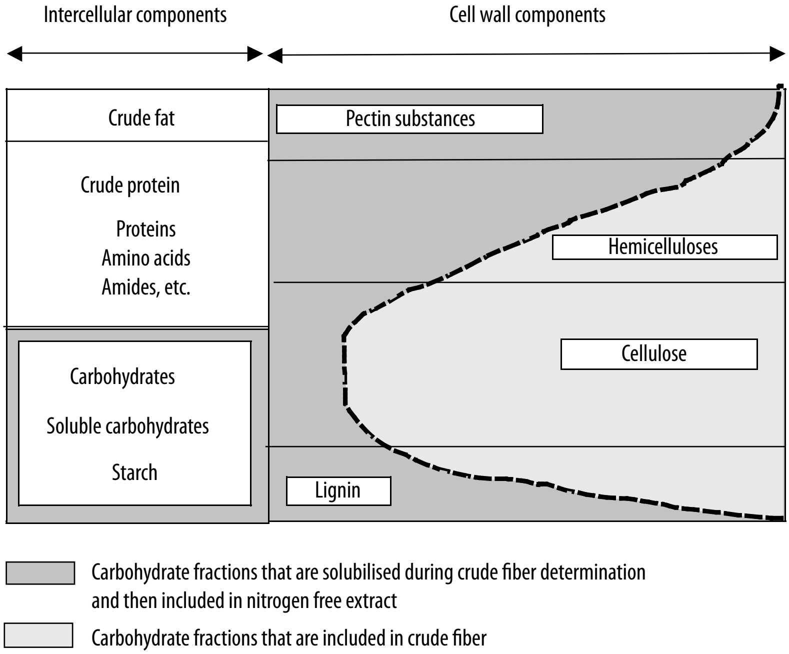

Figure 12.1. Diagram of organic matter components of feedstuffs that are partitioned using standard methods of determination.

12.1.1.1 Intracellular components

There are soluble carbohydrates (mainly sugars) in all feeds, but their contents range from 2 to 60% of DM (Chapter 16, Appendix 4). Starch, a complex carbohydrate, is contained mainly in grains, seeds and their by-products, as well as roots and tubers. Their contents range between 1 and 85% of DM (Chapter 16, Tables). Crude fat (or lipids) content ranges from1 to 46% of DM in oil seeds and their by-products (Chapter 16, Tables) whereas it is less than 5% of DM in other feeds (Chapter 16, Appendix 5). About 50% of crude fat is unsaturated fatty acids. The proportions of linoleic acid (C18:2) and linolenic acid (C18:3) are very high in some oil plants (Chapter 16, Appendix 6).

Crude protein content of feeds ranges between 5 and 60% of DM. Crude protein of feeds contains protein and non-protein nitrogen (NPN). Non-protein nitrogen content is high in the aerial part of plants and in root species, whereas the content is low in seeds. Non-protein nitrogen represents 15 to 20% of total nitrogen of green forages. This proportion is higher in stems than in leaves, in legumes than in grasses. Non-protein nitrogen is composed mainly of amides and free amino acids, as well as peptides with low molecular weight and amines. Their contents rise in hays, but more dramatically in silages when they are degraded by plant protease enzymes during pre-wilting, followed by bacteria during the fermentative process of ensiling.

Protein of forages represents 75 to 80% of total N. These proportions decrease in silages due to more intense fermentation. Most of N of cereals and legumes is in the form of protein. Cytoplasmic protein of the embryo of the seeds is similar to that of the aerial part of the plant. Protein of reserves is deposited in the form of proteic corpuscles in cells, of albumen, the aleuronic coat of cereals and in the cotyledon of legumes. These proteins (prolamins) are low in essential amino acids in whole crop cereals whereas in the (globulins) of oil and legumes seeds and their by-products they are high.

12.1.1.2 Cell wall components

Cell wall contents of straws and certain seed hulls range between 15 and 95% and from 60 to 90% DM respectively whereas, for concentrates, it only varies from 15 to 45% DM. Cell wall content of forages is intermediate ranging from 30 to 80% DM.

12.1.1.3 Chemical analysis of feeds

The aim of feed analysis is to determine the content of key components to routinely predict their nutritive value in order to formulate balanced diets, which meet the nutrient requirements of horses.

Feed analyses are carried out by laboratories which necessarily follow simple routine methods based on scientific work published in the literature. These methods are recommended in Europe by the European Union and/or the French association for normalisation (AFNOR) approved in France by the French official survey division (DGCRRF), INRA and AFZ (Table 12.1). A few new methods are also listed by the French interprofessional association for analytical methods (BIPEA, Genevilliers, France, www.bipea.org). Laboratories routinely compare their results during ring tests managed by BIPEA.

Water content and dry matter determination

Water content is measured in an initial step when the sample is delivered to the laboratory (Table 12.1). Water content represents the loss of mass when the samples are subjected to 103±1 °C during 4 hours in an oven. However, silages and sugar rich feeds should be managed in a particular way.

Silages contain organic volatile products (ammonia, volatile fatty acids, alcohols and lactic acids: Table 12.2), which are lost during the drying process recommended previously. If the above mentioned drying process is used DM content may be underestimated by 2 to 5%. DM should be corrected using data from the complete evaluation of the quality of fermentation of silages (Table 12.2).

Compound feeds, whose sugar content is over 4% through the inclusion of molasses or ingredients rich in sugars such as carobs, hydrolysed cereals products, should only be dried under partial vacuum at 80-85 °C using either dehydrating products or hot and dry air flux.

In all situations analysis should be conducted using officially approved laboratory equipment.

Ash and organic matter content

Ash (AS) content is measured using the weight of the residue obtained after incineration of the feeds in an oven for 6 h at 550±10 °C (Table 12.1). Ash content has no particular nutritional significance for mineral diet formulation. Specific measurements of mineral content (Ca, P, Mg, etc.) should be performed.

Table 12.1. Summary of the principal methods used to measure the chemical characteristics of the feeds (INRA, 1981; Sauvant *et al*., 2004).

Moisture	Methods based on desiccation such as AFNOR NF V18-109 (1982) for usual feed materials
Minerals or ash	Incineration such as AFNOR V18-101 (1977a)
Crude protein	Method based on mineralisation of nitrogen, such as Kjeldahl method (i.e. AFNOR NF V18-100, (1977b) or the Dumas method (AFNOR NF V18-120, 1997d). The crude protein content is obtained by multiplying total nitrogen by 6.25.
Amino acids	Acid hydrolysis (HCl, 6N) followed by chromatography. There are many methods with variations in duration (24-48 hours) and temperature (110 to 145 °C.) Methionine and cysteine are obtained after performic acid oxidation and tryptophan after alkaline hydrolysis.
Crude fiber	'Weende' methods, based on acid hydrolysis followed by alkaline hydrolysis such as AFNOR V03-040, 1977c; method CEE, directive 92/89 for forages and AFNOR NF V03-40 (1993) for raw materials (i.e. ingredients).
Cell wall components by Van Soest	Methods derived from the sequential method described by Van Soest (AFNOR NFV18-122, 1997c):
	NDF (Neutral Detergent Fibre): cell wall materials obtained by the action of dodecyle sulfate in a
or	neutral medium, sometimes with the use of enzymes (amylase et protease).
Fibersac for forages	ADF (Acid Detergent Fibre): ligno-cellulose obtained by the action of cetyletrimethylammonium bromide (CTAB) acidified part. In a medium acidified by H_2SO_4 72%. This is performed on the NDF residue.
	ADL (Acid Detergent Lignin): lignin estimated after destruction of true cellulose by H_2SO_4 72% in the ADF residue.
Water insoluble cell walls	Cell walls obtained by the AFNOR NF V18-11 (1989) method including treatments with alpha-amylase and a protease, followed by the removal of lipids.
Starch	Ewers polarimetric method (EC, 1972; modified on 27/11/1980). The enzymatic method is sometimes used. A value of zero is given for starch – free materials such as oil seed meals and sugar beet pulp.
Total sugars (soluble sugars)	Ingredients (raw materials): e.g. total sugars obtained by the Luff-Schoorl method (ethanol extraction). However there are other enzymatic methods.
	Forages: soluble sugars in water or in alcohol are measured by using their reduction power after hydrolysis for 30 mn in HCl 0.2 N medium. For lucerne and tropical forages starch should be primary assayed using the enzymatic method after extraction of water soluble sugars.
Crude fat	Methods based on the extraction of lipid substances by a solvent such as diethyl ether; hence the usual appellation of 'ether extract'. For most feed materials, the reference method in France is AFNOR NF V18-117, (1997b). The use of HCl hydrolysis before extraction is sometimes used for some products.
Fatty acids	Methods based on the use of chloroform/methanol, methylation and extraction of methyl-esters followed by chromatography.
Minerals and trace elements	Spectroscopic methods adapted for each mineral, such as AFNOR V18-108 (1984) for calcium and AFNOR NF V18-106 (1980) for phosphorus.
Phytate phosphorus	Organic plant phosphorus bound to phytic acid. Phytate phosphorus is calculated as 28.2% phytic acid. Different methods can be used to measure phytic acid: precipitation of an iron composite or HPLC.

Table 12.2A. Correction of dry matter content of silages: methods used for the determination of different volatile products content of silages (Demarquilly and Jarrige, 1981).

Ammonia (N-NH_3)	Method Conway (1957)
Soluble nitrogen (soluble-N)	Method Kjeldhahl or method Dumas
Lactic acid	Method Noll (1974)
VFA and alcohols	Gaseous phase chromatography (Jouany, 1982)

Table 12.2B. Correction of dry matter content of silages: correction after extended analysis of fermentation quality (Demarquilly and Jarrige, 1981).

In this case the following information should be known:

the botanical family of the forage;
the silage pH;
NH_3, VFA (volatile fatty acids), alcohols, lactic acid content;
the drying condition;
the non-corrected DM (DM_{nc}).

The correction should be implemented as following:
DM corrected = DM non-corrected × correction factor
Correction factor = 1000 + losses in the oven /1000 (losses in g)
Losses in the oven should be calculated as followed:
Losses = amount of volatile products × volatility

The amount of volatile products in g/kg DM_{nc}. is assayed. Those products are:

NH_3
VFA (acetic, propionic, butyric, etc.)
alcohols
lactic acid
formic acid is discarded as it has no nutritional relevance and the content in silages is always low. Volatility coefficients are very variable.

I. Drying at 80 °C

small volume oven – 48 hours no ventilation;
large volume oven – 24 hours with ventilation.

Volatility coefficient (×100) of different silages

Silage	Product	pH of silage						
		3.8	4.0	4.2	4.4	4.6	4.8	5.0
Grasses	NH_3	43	52	62	71	81	90	100
	VFA	92	87	83	78	73	69	64
	alcohols	100	100	100	100	100	100	100
	lactic acid	14	14	14	14	14	14	14

Table 12.2B. Continued

Silage	Product	Acetic acid content (g/kg DM_{nc} of silage)		
		10	20	30
Corn	NH_3	38	38	38
	VFA	68	80	92
	alcohols	100	100	100
	lactic acid	11	11	11

Example: grasses silage with pH=4.2
Losses = $NH_3 \times 0.62 + VFA \times 0.83 + alcohols + lactic\ acid \times 0.14$

		Losses
NH_3	2×0.62	1.24
VFA	30×0.83	24.90
Alcohols	15×1	15.00
Lactic acid	60×0.14	8.40
		49.54 = ~50

Correction factor = (1000 + 50) / 1000 = 1.050

If DM content determined in an oven is 18.0%, the true DM content is $18 \times 1.050 = 18.90\%$. In contrast, if CP content (determined in fresh materials) and crude fibre are 12 and 28%, respectively, in non-corrected DM, the true contents are 12/1.05 = 11.4% and 28/1.05 = 26.7%.

Example: corn silage with 18 g/kg DM acetic acid
Losses = $NH_3 \times 0.38 + VFA \times 0.78 + alcohols + lactic\ acid \times 0.11$
In these equations NH_3, AGV, alcohols and lactic acid content are expressed in g/kg DM_{nc}.

II. Drying at 100 °C
In this case volatility coefficients are not accurately known. Volatility of lactic acid depends on drying duration. Presently the following volatility coefficients are used:

Silage	Product	Volatility coefficient
Grasses and corn	lactic acid	
24 hours oven		20
48 hours oven		40
All silages	alcohols	always 100
Grasses	NH_3	
Good conservation		75
Poor conservation		100
Corn		60
All silages	VFA	100

Table 12.2C. Estimated content of volatile products in silages.

If the analysis of fermentation products is not complete or have not been assayed the following estimated amounts may be used.

Silages	Product	Content (g/kg DM)
Grasses	lactic acid	75-90
Corn (30-40% DM)	lactic acid	50
Grasses	alcohols	15-30
Corn (30-40% DM)[1]	alcohols	20-5
Grasses (good conservation)	NH_3	1-2
Corn (good conservation)	NH_3	1

[1] The content of alcohols decreases with increasing %DM; the estimated contents are given for 30 and 40% DM, respectively.

In contrast OM content can be calculated:

OM = DM – AS

Ash content is also used to detect soil pollution of forages.

Crude protein content

The Kjeldahl method is the reference for measuring total nitrogen (N) (Table 12.1). Organic N is mineralised by sulphuric acid. The ammonia N which is formed (ammonium sulphate) is removed with alkali then measured by titration. The method is time-consuming. Hence laboratories are using a colorimetric measurement of ammonia with auto-analyser equipment.

Crude protein content is conventionally calculated by multiplying ammonia content by 6.25. This coefficient comes from the ratio 100/16 because it is assumed that the nitrogen content of crude protein, which is measured, averages 16%.

This measurement has been semi-automated (Dumas method). Pelleted samples are incinerated under oxygen in a combustion tube at high temperature. The components which are formed (CO_2, H_2O, NO_2 and SO_3) are flushed by a gas vector (helium). The mixture goes through a Pyrex wool filter, which traps ash and impurities. Water is eliminated by a condenser and the different gases are homogenised in a ballast tank.

A representative fraction is sampled and flushed towards different traps:

Hot copper (750 °C) reduction of N oxides results in N_2 and the trapping of sulphured components and oxygen:

$2\ Cu + O_2 \rightarrow 2\ CuO$
$2\ Cu + NO_2 \rightarrow 2\ CuO + ½\ N_2$

Lecosorb (NaOH) and anydrone (perchlorate of magnesium) traps CO_2 and residual water.

The N_2 is detected by thermo conductimetry using a catharometer apparatus.

This is a fast method. The N content measured by the Dumas' method is, on average, 4% higher than that determined by the reference method. As the results are very consistent between the two methods N kjeldahl (Y) can be predicted from N Dumas (X) using the following relationship designed at INRA (Aufrere and Dudilieu, unpublished).

$Y = 0.9755\ X - 0.511$ $R^2=0.999$; n=49 (forages and concentrates)

Water soluble carbohydrate content

Water soluble carbohydrates (WSC) in forages (sugars and fructans) are determined using the reducing power of the extract following hydrolysis with hydrochloric acid (HCl 0.2 N) during 30 minutes. Somogy's method (1952) can be used as well.

Cytoplasmic carbohydrate content can be approximated in forages without determination using the results of standard analysis because WSC is the most variable component of the undetermined fraction in forages.

$WSC = DM - (AS + CP + CF)$

The range of WSC contents in forages is also given in Chapter 16, Appendix 4.

Carbohydrate content in concentrates that are soluble either in water or in alcohol is determined using routine methods, such as reducing power, total carbohydrates analysis, specific enzymatic analysis of glucose or of saccharose.

Starch content

Tropical forages can contain starch (STA). Following extraction of WSC, STA content is determined using an enzymatic method (Thivend *et al.*, 1965). All the starchy components can be assayed with this method whatever their solubility in alcohol or water and whatever other types of carbohydrates are in feeds (e.g. fructans, alpha-galactosides, saccharose, etc.). Using this method, STA is broken up then subjected to amyloglucosidase action. The glucose formed is assayed with a spectrometer using the gluco-oxydase method.

The principle of the polarimetric method is to determine the rotative power of the medium obtained following STA hydrolysis with hydrochloric acid. However, STA content is overestimated by 3 to 5% of DM in ingredients containing easily hydrolysable hemicelluloses, such as bran. In addition, STA content has been determined in feeds, such as beet pulp, which contains none.

Crude fibre content

Crude fibre (CF) content is routinely assayed using the Weende method (Henneberg and Stoheman procedure). Crude fibre results from a double hydrolysis sequentially performed with an acid solution (H_2SO_4, 1.25%) and then a diluted alkaline solution (NaOH or KOH, 1.25%) (Table 12.1).

Crude fibre is a cellulosic based residue which is partitioned into cellulose (70-90%), lignin (5-10%), hemicelluloses (5-10%) and crude protein (1-3%). This gives an overestimation of cellulose. This manual procedure is time-consuming. It is increasingly substituted by the Van Soest method even though it has not yet been entirely automated. Greater biochemical or nutritional significance is not yet proven.

Cell wall partitioning (fibre and lignin)

The Van Soest procedure (Table 12.1) uses, in sequence, several detergents:
- neutral detergent to extract, from a water medium, a residue which represents total cell wall or NDF, so called neutral detergent fibre;
- then acid detergent (H_2SO_4, N) to extract a new residue ADF, so called acid detergent fibre;
- and ultimately a solvent such as permanganate to extract lignin or ADL, so called acid detergent lignin.

These different steps of the procedure can be implemented either independently, called the direct method, or subsequently, called the sequential method. The determination of each fraction, using the two methods, is fairly well correlated. However, the values obtained with the sequential method are slightly lower than those determined with the direct method.

The initial Van Soest procedure (sequential method) is also time-consuming and manual as is the Weende procedure. In contrast, procedures have been technically improved to assay a greater number of samples in the same time thanks to two new protocols proposed subsequently: the Fibertec system in 1975 and then the Fiberbag system in 1996.

Relationship between total cell wall content, acid detergent fibre content and crude fibre content

Equations have been designed for green forages at INRA using large sets of data where total cell wall content (NDF) and acid detergent fibre (ADF) content or crude fibre (CF) was assayed using sequential procedure analysis (Goering and Van Soest, 1970) or weende method. These equations can be also applied for preserved forages, using correcting factors for the slopes in the equations dedicated to green forages, to take care of the effects of the preservation methods (Table 12.3). NDF and ADF content of green forages can also be predicted with a calibration population that has been established using near infrared spectroscopy (Table 12.4).

Crude fat or ether extracts

Crude fat (EE) is determined under reflux of ethyl ether using the Soxhlet apparatus. However, the extract does not contain all the lipids (Table 12.1). It does, however, include non-lipid components solubilised by the solvent, such as pigments which may account 50% of the extract in forages; or

Table 12.3. Relationships between total cell wall content (NDF, g/kg DM); acid detergent fibre (ADF, g/kg DM) and crude fibre (CF, g/kg DM) of green forages (INRA, 2007).[1]

Equations	R^2	Residual standard deviation
Natural grassland (n=28)		
NDF = 0.90 CF + 306	0.96	9.9
ADF = 0.83 CF + 76	0.99	4.0
CF = 1.19 ADF – 88	0.99	4.8
Grasses (n=147)		
NDF = 1.14 CF + 260	0.88	17.1
ADF = 0.95 CF + 40	0.93	10.8
CF = 0.98 ADF – 19	0.93	11.0
Legumes (Lucerne, red clover) (n=34)		
NDF = 0.575 CF + 320	0.92	9.3
ADF = 0.579 CF + 147	0.91	9.6
CF = 1.572 ADF – 209	0.91	15.8
Whole plant corn silage (n=254)		
NDF = 1.30 CF + 201	0.73	18.1
ADF = 1.06 CF + 8.2	0.92	7.1
CF = 0.87 ADF + 9.5	0.92	6.4
Other whole crop cereals (n=29)		
NDF = 1.24 CF + 228	0.98	9.6
ADF = 0.97 CF + 55	0.98	7.1
CF = 1.01 ADF – 50	0.98	7.3

[1] The relationship between ADF and CF can be applied regardless the types of the preservation of the green forages. For prewilted or wilted and wrapped silages of grassland and grasses, the slope of the equations between NDF and CF should be decreased by 0.05. For hays, the slope of the equations between NDF and CF should be increased by 0.07.

Table 12.4. Characteristics of near-infrared spectoscopy calibration of total cell walls (NDF) and acid detergent fibre (ADF) contents performed on green forages.[1,2]

	Composition					Statistical parameters			
	n	Mean	SD	Min.	Max.	Sec	R^2	SEcv	r^2
NDF	220	540	75	350	714	10.7	0.98	14.1	0.97
ADF	220	292	48	174	428	9.1	0.96	11.7	0.94

[1] Calibrations models are specific for the spectrometer that is used to develop the calibration population (see Section 12.1.2.4 of this Chapter and Table 12.11).

[2] Abbreviations used: SD = standard deviation; Min. – Max. = range; SEc = standard error of calibration; R^2 = coefficient of determination in calibration; SEcv = standard error of cross-validation; r^2 = coefficient of determination in cross-validation.

organic acids, oils and alcohols in other feed materials. This extract represents an overestimation of lipid content in feeds. It is not used to predict the energy value of forages. Actually, hexane or oil ether heated to 55-60 °C is substituted for ethyl ether to improve the analytical work and the clarity of the extract.

Nitrogen free extracts

Nitrogen free extracts (NFE) are the sum of intracellular carbohydrates (soluble and starch) and more than half of the cell wall components (Figure 12.1). It is the difference between 100 and all the other components mentioned previously.

NFE = 100 – (CP + CF + EE + AS)

It has no nutritional significance because it incorporates all the approximations of the methods used to assay the other components.

Minerals and trace elements

Minerals (Ca, P, Mg and Na) and trace elements (Cu, Zn, Mn, Se and Co) are assayed by spectroscopic methods adapted to each component (Table 12.1).

The standard analysis of feeds

This is the minimum analytical set required to characterise feeds and to predict their nutritive value. This set consists of the determination of the content of water, ash, crude protein, crude fibre and ether extract. The methods of determination that are officially accepted should be implemented according to the accurately described procedures (Table 12.1). Repeatability of results is established when two subsequent determinations of the same component in the same sample carried out in the same laboratory agree. The reproducibility of results of determination of the same component in the same sample achieved by several laboratories during a ring test supervised by the interprofessional association for analytical studies (so called BIPEA in France: www.bipea.org), should be conducted yearly.

Feed sampling for laboratory analysis

Samples must be representative of feed stocks of concern. Implementation of the following sampling protocol is recommended:

- Several samples of the same size should be collected uniformly over the stock using the means (hand, drill or outflow of feed storage system, etc.) most adapted to the type of feeds and their storage form (silos, bales and bags, etc.).
- All samples should be amalgamated to provide a new unique sample of 1 kg for forage and 200 g for concentrates destined for laboratories for analysis.
- Conditioning and prompt delivery of samples is recommended: for dry samples (hay or concentrates) a cardboard box may be used; for moist samples (silages, haylages) a plastic bag fitted in a box containing packed ice if the time-delay for transportation is more than 48 hours.

- Good preservation of samples in all situations is definitely recommended: samples are never stored in plastic bags more than 48 hours at ambient temperature, especially in the sun. Silages samples should be refrigerated.

Laboratory analysis will be carried out using sub samples (0.5 to 1.0 g) obtained after grinding the initial sample. Grinding should be carefully conducted to prevent water and dry matter losses as dust or volatile products. If water content of the sample is over 10-15% of gross weight (for example silages), predrying at 60-70 °C is required. All the samples are ground through a 0.8 to 1.0 mm screen before analysis.

Opportunity for laboratory analysis

Analysis is costly. The cost can be reduced when sufficient information about feeds is obtained at the start of diet formulation.

For forages, knowledge of type (permanent or temporary grasslands), species for temporary grasses (ryegrass, fescue, etc.), growth cycle (or cutting number) or the date at harvest, etc., permits a satisfactory approximation of the chemical composition and the nutritive value using the tables displayed in Chapter 16.

For concentrates the tables provide average values for the chemical components established by the French Association of Animal science (Association Française de Zootechnie: AFZ in French). These data came from analyses carried out by feed companies and organisations (Sauvant *et al.*, 2004). It is always possible to predict the content of some components using the relationships described between those components and other major components (Sauvant *et al.*, 2004). The nutritive value of concentrates is displayed either in the tables devoted exclusively to concentrates for all farm animals including horses (Sauvant *et al.*, 2004) or in the tables given in Chapter 16 dedicated only to horses.

12.1.2 Digestibility: major determinant criteria of energy or nitrogen value of feeds

12.1.2.1 Digestibility concept

The digestibility of a feed is related to the digestibility of each of its chemical components. The digestibility coefficient of the cellular content of plants is close to one. Water soluble carbohydrates are totally digestible and starch digestibility is also high (about 70 to 90%). The true digestibility of crude protein is very high too and ranges between 82% for forages to 95% for concentrates. The true digestibility of lipids falls in the same range but it is not of much concern for forages as their lipids content is low.

The apparent digestibility of cellular contents and its components is much lower than 100% because of excretion in the faeces of endogenous (enzymes, mucus of intestinal epithelium, etc.) or microbial (crude protein) organic matter. The apparent digestibility ranges between 10 to 40% when cellular content rises from 20 to 50% (Figure 12.2). Indeed digestibility of crude protein increases from 30 to 75% when crude protein content increases from 5 to 25% DM.

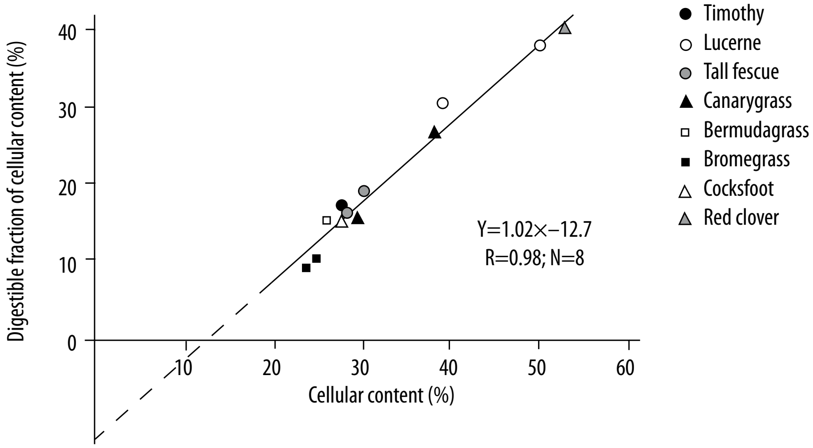

Figure 12.2. Relationship between digestible fraction of cell contents and the cellular content of forages (Fonnesbeck, 1969).

Cell walls are degraded in the large intestine. The range of degradation varies according to plant tissue, and related species, maturity state, etc. The lower digestion of cell walls in horses than in ruminants is explained by the lack of rumination and the short mean retention time of cell walls in the large intestine of horses (24 to 30 hours) compared to that of ruminants (48 to 72 hours).

In horses as in ruminants one can distinguish, from a nutritional point of view, in the cell walls (Figure 12.3):

- A fraction which is potentially digestible. These are the tissues with thin walls, which are composed of polysaccharides; none protected from microbial degradation by lignin or cutin.
- A fraction which is totally indigestible. These are the tissues with thick walls whose polyholosides are protected from bacterial degradation by lignin and cutin.

The content of the indigestible fraction of walls in forages is as high in horses as in ruminants. This content is higher in stems than in leaves. It increases with age and it is higher in grasses than in legumes when compared at the same lignin content.

In contrast the content of the indigestible fraction of walls in concentrates is low but quite variable. It is particularly low in cereals grains, legume and oil seeds. It is higher in their by-products (bran, meals) but depends on milling size of cereals grains and the degree of husking of oilseeds before oil extraction. Roots and their by-products (beets and beet pulps) are low in indigestible walls.

The digestibility of feeds is highly related to their indigestible cell wall content, principally their lignin content. CF is the most useful analytic criterion in estimating cell wall content of feeds because it is a good indicator of digestibility: The greater the CF content of feeds the lower their digestibility (Figure 12.4). But the assay is lengthy, as a result simpler and faster assay criteria were proposed. These criteria are: total cell wall content (NDF), lignin-cellulose (ADF) and lignin (ADL). Digestibility of organic matter is closely correlated with these criteria.

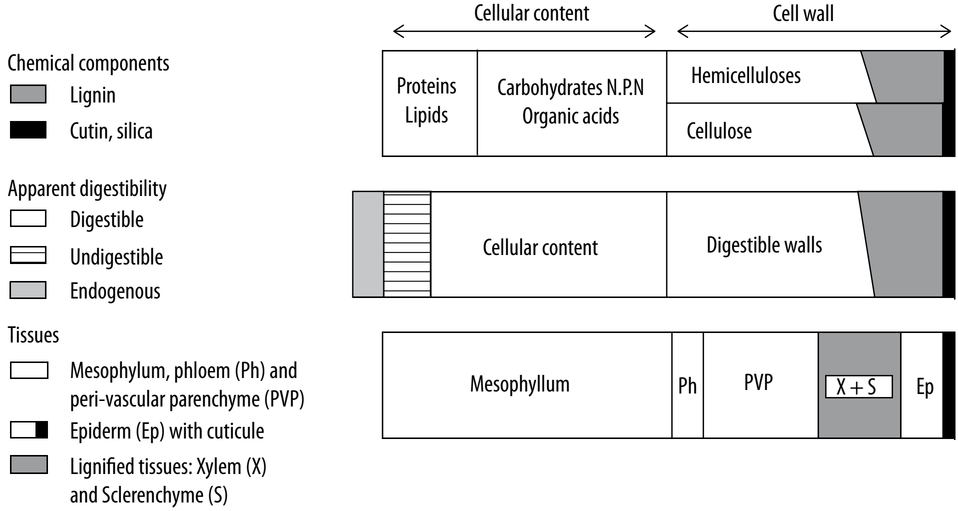

Figure 12.3. Simplified diagram of anatomical and chemical components (organic) of a forage and their digestibility (digestibility coefficient of organic matter: 0.70) (Jarrige, 1981).

12.1.2.2 Digestibility of organic matter

Forages

The digestibility of green forages decreases with age during the vegetation cycles. This evolution is related to the variation in chemical composition resulting from the evolution of the morphologic composition. Cell wall content which is less digestible rises with the increase in stem proportion at the expense of the proportion of leaves whose cellular content is high (Figures 12.5 and 12.6).

The digestibility of preserved forages is related to that of the corresponding green forage at harvest (and thus its age) and to a lesser extend to harvest conditions.

The relationship between the digestibility of organic matter and the chemical composition was designed for hays from data obtained at INRA using a standardised experimental protocol. Six light breed horses were fed *ad libitum* with the forages that were studied during three weeks, which included two weeks adaptation and one week of measurement using total faeces collection. The relationship calculated from 72 data sets between the digestibility of organic matter and crude fibre content is negative (Table 12.5). It is different for grasses and legumes. Such relationships do exist for green forages but the number of data obtained at INRA is insufficient (n=14) to propose specific equations with as much accuracy as for hays.

The digestibility of regrowth of all forages is always lower than that of the corresponding forages at the early stage of the first cycle, but it decreases slower for leafy regrowth than for stemmy regrowth (Figure 12.7). In temperate zones, the influence of the variety is low and environmental influence is

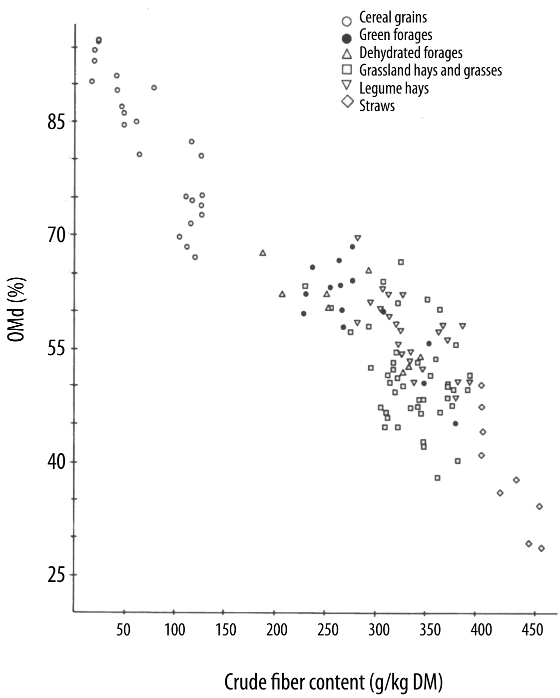

Figure 12.4. Relationship, in horse, between the digestibility coefficient of organic matter (OMd in %) and crude fiber content (Martin-Rosset *et al.*, 1984).

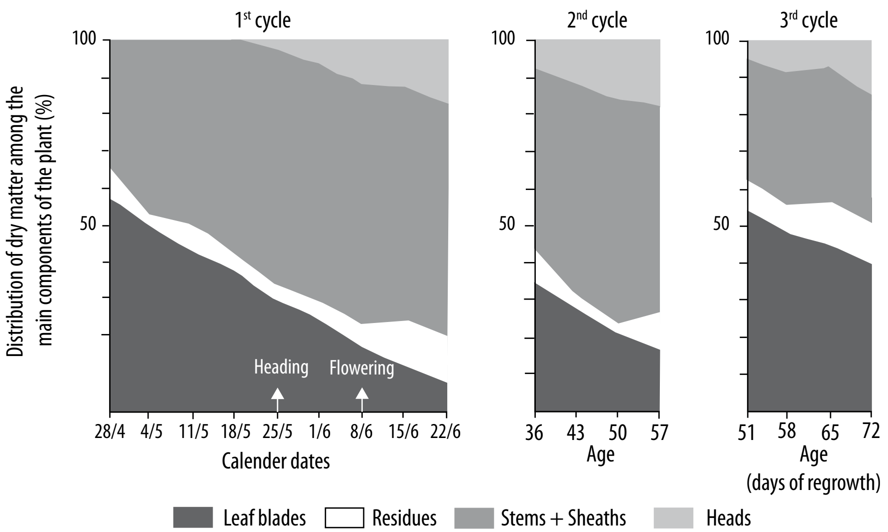

Figure 12.5. Variation with age during the subsequent vegetation cycles, of the morphologic composition of Italian ryegrass (Demarquilly and Andrieu, 1988).

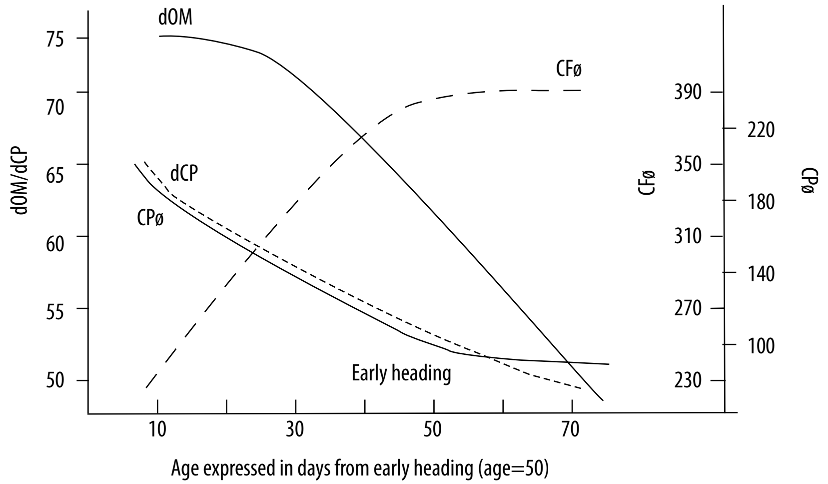

Figure 12.6. Variation of the digestibility of organic matter (OMd) and of crude protein (CPø) and crude fibre (CFø) in g per kg of organic matter, of timothy with age (x) during the first vegetative cycle (Martin-Rosset *et al.*, 1984).

Table 12.5. Relationship between the digestibility of organic matter (OMd, %) of hays and their crude fibre content (CF g/kg DM) (Martin-Rosset *et al.*, 1984).

Botanic type	n	Range of CF content	Equations[1]	SE_y[2]	R
Grassland[3]	28	230-375	OMd = 87.89 – 0.1180 CF	±4.1	0.711
Seeded species: *Graminea*	19	295-390	OMd = 81.51 – 0.0792 CF	±6.3	0.422
legumes	25	285-395	OMd = 90.52 – 0.0995 CF	±3.7	0.666
All hays	72	230-395	OMd = 78.33 – 0.0746 CF	±6.0	0.414

[1] Adding crude protein content to crude fibre content does not improve the precision of the equations displayed in the table.

[2] SE_y: standard error.

[3] In practice, the equation can be used for pre-wilted silages and haylages (and to some extend for maize silages).

limited at least in the first cycle because the digestibility of a plant at a designated vegetation stage is nearly the same, whatever the location, year and amount of nitrogen fertilisation.

The digestibilities of grass silages (pre-wilted or haylage) or of maize silages decrease only by 1 or 2 points compared to corresponding green forages at the same vegetative stage because the chemical composition changes little if harvest conditions are good (Chapter 11). The digestibilities of whole plant maize silages harvested at 30-35% DM following good vegetative conditions does not differ significantly to those of green forages, because the chemical composition is much less affected by ensiling process for corn silages than for grass silages (Chapter 11). In contrast, the digestibility of hays is 4 to 6 points lower than that of green forages because cell wall contents increase as do leaf

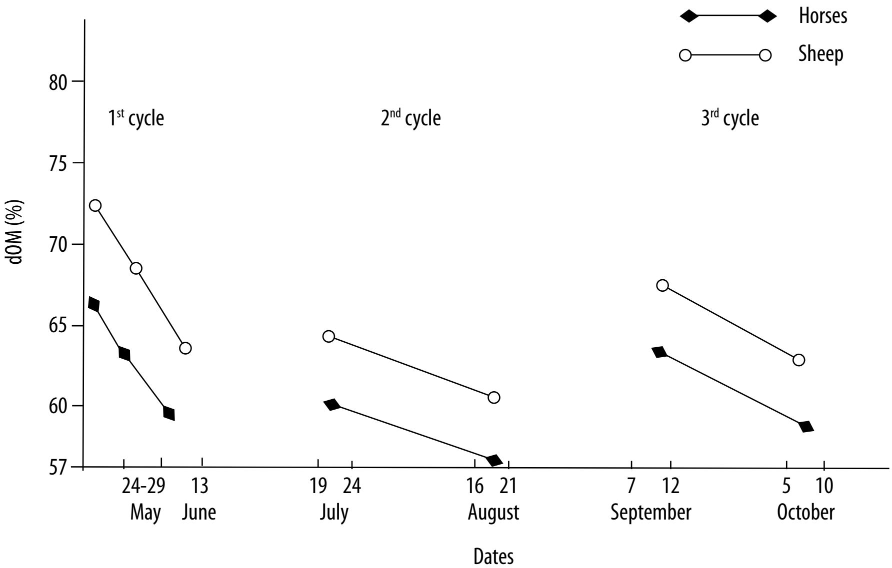

Figure 12.7. Change in digestibility of organic matter (OMd, %) of natural grassland during the seasonal stages and cycles of the forages for horses and sheep (Chenost and Martin-Rosset, 1985).

losses during haymaking. In contrast, digestibility is not significantly affected by dehydration because chemical composition does not change if processing is well managed.

Dry forages are most often fed to horses in the long form. But they can also be fed as other forms to make storage and handling easier or for incorporation into compound feeds. They can be subjected to different processing: directly compressed or compacted without any previous grinding or ground then pelleted using the appropriate respective die. Digestibility is affected by processing. However, there are few and controversial data because processing effects depend on feeding level: *ad libitum* vs limited. To date this has not been given much consideration.

Attempted improvement in the nutritive value of poor forages using chemical treatments has taken place over several decades, primarily for straws (Chapter 11). Treatment of straws with effective alkalis such as sodium hydroxide or ammonia break down linkages between hemicelluloses and lignin. As a result cell wall digestibility rises. In addition, the treatment improves the digestion of cellulosic fibre as it destroys the crystalline structure of cellulose.

Feeding horses with sodium hydroxide has been studied since the First World War and more recently refined (Chapter 11). Sodium hydroxide treatment improves digestibility of organic matter by 4 to 12 points depending on nitrogen supplementation of the diet.

Similar improvement of organic matter digestibility of straws is obtained with ammonia treatment. Ammonia-treated straws are more readily accepted by horses than those treated with sodium hydroxide (Chapter 11). Treatment with alkalis do not change crude fibre content of straws (Chapter 11). Hence, this criterion may be used to predict digestibility of treated straws.

Concentrates

Digestibility of concentrate feeds is also negatively correlated to crude fibre content, whatever the feeds grains (cereals) or seeds (legumes) and their respective by-products (Table 12.6).

Grains are processed according to different treatments (Chapter 9, Table 9.4) to permit or promote their digestion. Oats are an exception as native oats can be fed. Digestion coefficients of grains that are displayed in the tables are all simple processed grains (Chapter 16). The equations proposed to predict digestibility are all based on experimental data files obtained with processed grains. The influence of mechanical or thermal processes on organic matter digestibility of grains does not seem to be effective because the digestibility criterion is too global to detect it. The main effect is to raise the proportion of starch that is digested in the small intestine resulting in an increase in net energy value (Section 12.1.3.2 in this chapter).

12.1.2.3 Digestibility of crude protein

Forages

CP digestibility decreases with age during the first cycle because CP content falls with the decline in leaf proportion (rich in cellular content) and related increased proportion of stems (Figure 12.5

Table 12.6. Relationships between digestibility of organic matter (%) and chemical composition of ingredients (Martin-Rosset and Tran, extracted from Sauvant *et al.*, 2004).[1]

Feeds	n	Equations	RSD	R^2
All feeds	42	OMd = 89.0 - 1.01 CF	±7.1	0.674
		OMd = 85.7 – 0.959 CF + 0.117 CP	±7.1	0.692
		OMd = 69.2 – 0.538 CF + 0.352 CP + 0.214 CC	±6.5	0.745
Cereals	10	OMd = 93.2 – 1.68 CF	±1.3	0.987
		OMd = 99.3 – 1.67 CF – 0.553 CP	±1.4	0.992
		OMd = 47.0 – 0.223 CF + 0.345 CP + 0.530 CC	±0.2	0.969
Cereal by-products	17	OMd = 89.8 – 1.90 CF	±3.3	0.890
		OMd = 100 – 1.97 CF – 0.594 CP	±2.9	0.936
		OMd = 70.7 – 1.17 CF + 0.22 CP + 0.235 CC	±3.0	0.953
Legume seeds	10	OMd = 58.9 + 0.193 CF + 0.480 CP + 0.254 CC	±2.6	0.904
Cakes	14	OMd = 92.7 – 1.26 CF	±4.6	0.676
		OMd = 63.2 – 0.263 CF + 0.442 CP	±2.4	0.928
		OMd = 64.7 – 0.477 CF + 0.697 CP – 1.423 CC	±1.9	0.961

[1] CC = cytoplasmic carbohydrates (=soluble sugars + starch); CF = crude fibre; CP = crude protein; OMd = digestibility of organic matter; RSD = residual standard deviation (all in %DM (dry matter)).

and 12.6). In contrast, the digestibility of CP is higher early in all cycles than in the 1st cycle as the CP content is higher (Table 12.7). The amount of DCP will be always higher at the beginning of each cycle and during early regrowth.

The amino acid composition of plant protein is fairly constant according to the organ of the plant, botanic family, species or age of the plant. This composition is well balanced in essential amino acids.

The digestibility of crude protein decreases with the method of preservation for hays, and to some extent, silages (pre-wilted or haylage) when compared to the same green forage because the crude protein content declines in haymaking. As a result MADC content of grassland harvested at heading during the 1st cycle decreases by 5% for haylages, 14% for hays and 18% for pre-wilted silages. These effects are due to the increase in the proportion of CP fixed to indigestible cell walls of hays, or in the proportion of soluble CP in silages that does not provide amino acids for the animal (see also Chapter 11).

There is no modification of chemical composition with dehydration under proper drying conditions that prevent Maillard linkages between protein and carbohydrates of plants, primarily a concern for legumes. Digestibility is not significantly affected compared with that of the corresponding green forage at the same vegetation stage.

The influence of processing (compacted, pressed or pelleted) forages on digestibility is still controversial as it depends on the feeding level of horses: limited vs free choice. Owing to the lack of data these modifications are not considered.

Table 12.7. Average content of non-digestible crude protein (NDCP g/kg DM) and relationship between digestible crude protein (DCP g/kg DM) and crude protein content (CP g/kg DM) and crude fibre (CF g/DM) in forages (Martin-Rosset *et al.*, 1984).

Feeds	n	NDCP content	Equations	RSD[1]	R^2
Green forages[2]					
Permanent grassland and seeded grasses	14	48	$DCP^4 = -27.33 + 0.8614\ CP$	±7.7	0.967
			$DCP^4 = -74.52 + 0.9568\ CP + 0.1167\ CF$	±6.3	0.980
Hays[3]					
Permanent grassland and seeded grasses	47	43	$DCP^4 = -25.96 + 0.8357\ CP$	±7.1	0.968
Legumes	25	50	$DCP^4 = -29.95 + 0.8673\ CP$	±9.2	0.933
All hays	72	46	$DCP^4 = -27.57 + 0.8441\ CP$	±8.6	0.964

[1] RSD = residual standard deviation.

[2] In practice, the equation can be used for haylages (and to some extend for maize silages).

[3] In practice, the equation can be used for pre-wilted grass silages.

[4] Crude fibre content does not significantly improve the precision.

The DCP content of ammonia-treated straws is not improved even though the nitrogen content increases because ammonia fixed on straws is transformed into urea in horses that is recycled via the entero-hepatic cycle.

Concentrates

The digestibility of crude protein in grains, the DCP content, is positively and linearly related to their crude protein content. At the same crude protein content the digestibility of crude protein is higher in concentrates than in forages. It can be variable depending on processing. Heavy thermal processing reduces crude protein digestibility (Maillard reaction). Digestible crude protein (g/kg DM) content of grains is linearly related to crude protein content (g/kg DM). There are few data available in published trials using such heavy processes. Inclusion of the crude fibre criterion in the prediction equation does not improve the precision (Table 12.8).

The digestibility of crude protein (dN) of plant by-products (cereals or oilseeds and legumes) can be influenced by cell wall content, namely the indigestible fraction (ADF), hence by the process implemented: wheat feed flour vs wheat bran, dN = +5 points; rapeseed meal partially dehulled, dN = +4 points.

The digestibility of crude protein in legumes and oilseeds is the most often very high owing to the high crude protein content (200 to 550 g/kg DM). It can, however, be limited if the cell wall content is high, primarily the indigestible fraction (ADF), for example: lupin and rapeseed.

12.1.2.4 Method for prediction of the digestibility of forages

The digestibility of organic matter and crude protein of green and preserved forages, hence of their energy and nitrogen value can be predicted according to two methods:

1. Prediction only from botanic characteristics. We already know that digestibility depends mainly on their characteristics at harvest (species, cycle, age) and harvest condition for preserved forages. Thus, the nutritive value of forages can be predicted simply by reading the tables in Chapter 16, when this information is available. This approach is basic and does not require any chemical analysis to formulate diets.

Table 12.8. Relationship between digestible crude protein and total crude protein content in ingredients and prediction (Martin-Rosset, 2004; Martin-Rosset *et al.*, 2006).[1]

Feeds	n	Equations	RSD	R^2
All feeds	42	DCP = 10.7 + 0.911 CP – 0.121 CF	±8.6	0.959
Cereals	23	DCP = -2.68 + 0.833 CP	±5.4	0.969
Cereal by-products	17	DCP = -17.6 + 0.865 CP + 0.051 CF	±6.7	0.945
Oil and legume seeds	10	DCP = 2.59 + 0.844 CP – 0. 103 CF	±4.6	0.996
Cakes	14	DCP = -43.6 + 0.989 CP – 0.127 CF	±6.3	0.998

[1] CF = crude fibre; CP = crude protein; DCP = digestible crude protein; RSD = residual standard deviation (all in g/kg DM).

2. Prediction from chemical analysis. This method uses the relationship between the digestibility of organic matter and cell wall content (Table 12.9) on one hand, and between DCP and CP content on the other (Table 12.7). This method requires chemical analysis which should be carried out by qualified laboratories. This approach is recommended for the prediction of the digestibility of crude protein, because we know that for one species crude protein content has a wide range that is dependent on environment conditions.

Prediction of organic matter digestibility

Digestible organic matter content (DOM = OM × OMd) of forages is an essential criterion in the equations used to directly predict the UFC value with the highest accuracy (Section 12.1.3.2 of this Chapter).

The digestibility of organic matter of forages can be predicted either from crude fibre content (Table 12.6), or from cell wall fractions NDF and ADL (Table 12.9). The equations that are proposed have been calculated using the relationship between digestibilities measured *in vivo* and the chemical composition of a range of green and preserved forages studied at INRA. The accuracy is better using NDF and ADL, rather than CF content: ±2.5 and ±6.0, respectively.

The analytic methods used in assays for CF, NDF and ADL content are time-consuming. As a result an enzymatic method that mimics the total digestion of forages (or digestibility) has been designed at INRA (Table 12.10). This method requires three steps:

1. Pre-treatment with pepsin (Merck No 7190, Darmstadt, Germany: 1/1,000) in hydrochloric acid (0.2% pepsin in 0.1N HCl) in a water-bath at 40 °C during 24 hours;
2. Hydrolysis of starch contained in the previous mixture maintained in a water bath at 80 °C during 30 minutes;
3. Degradation of the mixture using fungal cellulase (Onozuka R10 extracted from *Trichoderma viride*, Yakult Honsha Co Ltd, Tokyo, Japan) during 24 hours in a water- bath at 40 °C and, ultimately, filtration and rinsing.

The determined degradability of dry matter of green or preserved forages is related to the digestibility of organic matter of the same forages measured *in vivo* at INRA (Table 12.10). The precision of the prediction of organic matter is high (±1.9) and it competes with the precision observed with chemical

Table 12.9. Prediction of the digestibility of organic matter (OMd, %) of green or preserved forages from their chemical composition (Martin-Rosset *et al.*, 1996a, 2012a).[1]

n	Range of variation of			Equation	RSD	R^2
	CF	NDF	ADL			
52	239-424	477-737	27-97	$OMd = 67.78 + 0.07088\ CP - 0.000045\ NDF^2 - 0.12180\ ADL$	±2.5	0.878

[1] ADL = lignin content (g/kg DM); CF = crude fibre; CP = crude protein content (g/kg DM); NDF = total cell wall content (g/kg DM); RSD = residual standard deviation.

methods. In addition, this method accounts for the effect of botanical family (grasses vs legumes) and preservation process (green forages vs hays). In the case of pre-wilted silages or haylages, the equation of prediction can be used and will include the correction established for green forages (Section 12.1.2.2 in this Chapter).

The accuracy of the prediction of OMd in the laboratory using this fast method is very useful as digestible organic content (DOM = OM × OMd) is a major criterion in the equations to directly predict the UFC value of forages (Section 12.1.3.1 of this Chapter).

Near infrared reflectance spectroscopy (NIRS) is increasingly used in routine laboratories for analysis. For prediction of OMd, reflectance (log 1/R) was measured at INRA on 52 samples of forages by NIRS according to the method of Norris *et al.* (1976). Two reflectance spectra were measured for each sample between 1,100 and 2,500 nm wavelengths with a monochromatic spectrophotometer (NIRSystems 6500). All the samples were ground through a 0.8 mm screen and oven dried (40 °C overnight) before recording the reflectance spectrum. The use of NIRS for predicting OMd in horses is potentially a very powerful method. OMd can be predicted using NIRS (Table 12.11) with an accuracy as high as the enzymatic method (Table 12.10) and higher than the chemical method using the best predictors (Table 12.9) (using the same data set, the RSD for the different methods was ±1.8, ±1.9 and ±2.5, respectively). However, there are limitations of using NIRS in routine laboratories. NIRS requires a minimum data base of 40 samples of different forages to design a standard calibration scale. Samples to be predicted should be represented in the calibration population. This also explains the differences found between reference and predicted values for legumes hays in a calibration model obtained with only grassland and gramineae hays (Martin-Rosset *et al.*, 2012a). Finally, calibration models are specific for the apparatus used for analysis. However, this last limitation is actually lifted using the protocols of standardization of the signal obtained in different NIRS instruments (Shenk and Wasterhaus, 1994). Hence, it is recommended in the early stage of implementation of a calibration population to collaborate with the promotor of such a model (D. Andueza, INRA, Clermont-Ferrand, France).

Table 12.10. Prediction of the digestibility of organic matter (OMd, %) of green or preserved forages from the digestibility of dry matter (dCell DM, %) measured with the pepsin-celullase method (Martin-Rosset *et al.*, 1996b, 2012a).[1]

n	Range of variation of			Equation	RSD[2]	R^2
	CF (g/kg DM)	NDF (g/kg/DM)	ADL (g/kg/DM)			
52	239-424	477-737	27-97	$OMd = -29.38 + \Delta + 2.30315\ dCell\ DM - 0.01384\ dCell\ DM^2$ $\Delta = + 4.12$ green forages (and silages or haylages) $\Delta = 0$ hays of grasses and of grasslands $\Delta = -2.61$ hays of legumes	±1.90	0.927

[1] ADL = lignin content; CP = crude protein content; DM = dry matter; NDF = total cell wall content.

[2] RSD = residual standard deviation.

Table 12.11. Characteristics of near-infrared spectrometry calibration of organic matter digestibility (OMd) performed on forages (Martin-Rosset *et al.*, 2012a). [1,2]

	n	Range of variation[3] (g/kg DM)			Range of *in vivo* OMd (%)	Model	Statistical parameters[3]			
		CF	NDF	ADF			SEc	R^2	SEcv	r^2
Absorbance (derived functions: Di)	52	235-424	477-737	272-452	40.8-65.9	Stepwise	1.82	0.931	2.00	0.920

[1] Green forages, hays, grassland, grasses and legumes (*Lucerne*).
[2] Calibrations models are specific for the spectrometer that is used to develop the calibration.
[3] Abbreviations used: DM = dry matter; CF = crude fibre; NDF = total cell walls; ADF = acid detergent fibre; SEc = standard error of calibration; R^2 = coefficient of determination in calibration; SEcv = standard error of cross-validation; r^2 = coefficient of determination in cross-validation.

Prediction of digestible crude protein

The prediction of digestible crude protein from crude protein content uses the equations set up for green and preserved forages (Table 12.7). The general equation can be used for pre-wilted silages whereas the equation designed for green forages should be used for haylages.

Particular case: grazed forages

Horses most often graze grasslands, but sometimes pastures seeded with rye grass or fescue alone or mixtures of rye grass, fescue, cocksfoot and clover. The prediction equations for OMd that are given in Tables 12.8, 12.9 and 12.10 are flexible and sometimes correction factors will even account for forage types (green, silages and hays) and families (grasses and legumes) (Table 12.10).

For grazed forages, the digestibility of grass varies continuously throughout the season. In horses, fewer measurements have been carried out on green forages than in ruminants, especially for the many vegetation stages. As a result, in order to predict with higher precision over a wider range of green forages, OMd can be predicted in horses from that measured in ruminants using equations based on simultaneous comparison carried out by INRA in both animal species (Table 12.12).

Hence OMd of grazed forages can be predicted using:
- either the flexible equations displayed in Table 12.8, 12.9 and 12.10;
- or relationships between horses and ruminants.

In contrast, digestibility of crude protein of green forages is little influenced by method for use (green or hay) in horses as in ruminants. As a result, there are comparable and close relationships between DCP and CP contents in both animal species: at the same CP content, DCP content of green forages in horse is similar to that in ruminants (Table 12.13).

Table 12.12. Prediction of the digestibility of organic matter (OMd_H, %) in horse from that in ruminant (OMd_R, %). (Martin-Rosset *et al.*, 1984).

Botanic type	n	Range of variation	Equations	RSD[1]	R^2
Grassland and seeded with grasses	18	$36<OMd_R<76$	$OMd_H = -14.91 + 1.1544\ OMd_R$	±2.3	0.960
Legumes	15	$55<OMd_R<66$	$OMd_H = -9.94 + 1.1262\ OMd_R$	±2.6	0.712

[1] RSD = residual standard deviation.

Table 12.13. Prediction of digestible crude protein content (DCP: g/kg DM) of green grassland and grasses from their crude protein content (CP: g/kg DM) in horses and ruminants fed simultaneously the same green forages (Martin-Rosset *et al.*, 1984).

	n	Equations	RSD[1]	R^2
Horse	12	DCP = -44.32 + 0.9645 CP	±7.2	0.978
Sheep	12	DCP = -43.89 + 0.9438 CP	±4.4	0.990

[1] RSD = residual standard deviation.

Finally DCP content of green forages can be predicted using:

- the value displayed in tables (Chapter 16);
- or prediction equations given in Table 12.7;
- or DCP content displayed in ruminant tables (INRA, 2007), especially to increase the range of seeded pastures and of grazed vegetation.

12.1.2.5 Method for prediction of the digestibility of concentrate (ingredients)

Digestibility of organic matter and crude protein can be predicted using two methods:

1. Prediction from botanic and technologic characteristics. If the ingredients have been processed with identified processes that correspond to those of feeds listed in the tables (Chapter 16 and 9), the OMd and DCP values given in tables can be used.
2. Prediction from chemical determination. If the processes are unknown or different from those mentioned for corresponding ingredients displayed in tables (Chapter 9 and 16) chemical analysis should be carried out in qualified laboratories. This method uses relationships which have been calculated between OMd and chemical composition (Table 12.6) on one hand, and between DCP and CP content (Table 12.8) on the other.

Prediction of organic matter digestibility

Digestible organic matter content (DOM = OM × OMd) of ingredients is an essential criterion in the equations used to directly predict UFC value (Section 12.1.3.2 of this Chapter). The digestibility of organic matter can be predicted from CF content alone or combined with CP content, including cyctoplasmic carbohydrates (Table 12.6). Unfortunately, there is not yet enough experimental data to propose equations including cell wall content assayed by Van Soest's method as for forages.

However, OMd can be predicted for ingredients, as forages, using also enzymatic methods. The principle of the method is the same as the one previously described and designed for forages, but the equation is different. The degradability of organic matter of ingredients determined in the INRA laboratory has been related to the OMd of the same feeds measured *in vivo* at INRA and Universities of Torino and Campobasso in Italy (Table 12.14). This equation should only be used for processed ingredients. The accuracy is satisfactory (±2-3 points) for ingredients, subjected to simple technologic processes (rolling, grinding, dehulling), but less satisfactory for feeds subjected to complex processes (±4-5 points). In practice, cereal grains are not used in a native state (especially barley and corn); oats are the exception. OMd for native or rolled oats given in the tables (Chapter 16) is the mean between the two forms. For the other cereal grains variability of prediction is understandable, when the influence of these processes on the proportions of quick vs slow digestible starch according to the temperature of treatment and the pressure is applied (Chapter 9, Table 9.4).

The general equation will have to be improved in the future by enlarging the range of feeds and especially, the processes studied. For dehydrated beet pulp, the following equation should be used: OMd (%) = dcell OM (%) + 17.6.

Prediction of digestible crude protein content

Chemical composition should be used to predict DCP using the equations given in Table 12.8.

12.1.2.6 Influence of diet composition

Digestibility of forage supplemented with 0 to 60% or 90% of concentrate for hay or maize silage based diets, respectively, is not significantly changed when the animal is fed a moderate feeding level: less than or equal to 2.5 times maintenance level (Martin-Rosset and Dulphy, 1987). As a result we state there are no negative digestive interactions on the digestibility of diets for feeding level ranging from 1 (maintenance) to 2, whatever the proportion of concentrate in the diet. In contrast, a negative effect on digestibility of the diet might be possible in horses fed a diet with more than of 60% concentrate, including cereals grains subjected to technologic processes, especially thermal treatment, over 2 times maintenance, because the intake of starch would range between 3.5 and 4.0

Table 12.14. Prediction of the digestibility of organic matter (OMd, %) of processed ingredients, from enzymatic degradability (dCell OM, %) measured by pepsin cellulase method (Martin-Rosset, Bergero and Miraglia, unpublished data).

n	Range of variation of CF (g/kg DM)	Equation	RSD[1]	R^2
17	23-195	OMd = 0.6837 dCell OM + 19.447	±5.6	0.560

[1] RSD = residual standard deviation.

g/kg BW. In this regard an increasing proportion of starch would reach the large intestine and then limit the cell wall digestion. But it addresses an exceptional case in the whole equine population: race horses racing short distances (sprints). Account is therefore taken of digestive interactions between forages/concentrates on the digestibility of hay-based diets. In race horses fed with only 30% of forages in a diet the potential effect is compensated by increasing the recommended allowances (Chapter 6).

12.1.2.7 Influence of the animal

The individual variability (e.g. standard deviation) of DM and OM digestion coefficients of the same average quality hay based diet (15% concentrate), fed to horses at maintenance or near two times maintenance, range from 1.6 to 2.3 points or from 3.1 to 4.3% of dDM or dOM coefficients. In contrast, the variability of dCP and dCF coefficients is much higher, 3.9 to 6.1 points or 5.2 to 12.9% of the coefficients. As a result, individual variability of dE coefficients range from 1.7 to 3.0 points or 3.4 to 5.8% of the coefficients (Martin-Rosset *et al.*, 1990).

Digestibility of grassland hay-based diets supplemented with moderate proportions of concentrate (≤20%) is not significantly different between light and heavy breeds (Martin-Rosset *et al.*, 1990). In contrast, digestibility in light horse breeds is slightly lower than in ponies: -2 points (Vermorel *et al.*, 1997). The discrepancy is again higher in donkeys fed poor forages (-5 points).

Digestibility of forage-based diets (20% concentrate) fed free choice to lactating mares is not affected, even when the mares are fed 2.5 times more than dry mares fed the same diet free choice. In contrast, digestibility is reduced by -5 points (10%) in pregnant mares during the 8^{th} to 11^{th} month of pregnancy compared to non-pregnant mares, also fed the same diet free choice (Martin-Rosset *et al.*, 1990). This result is due to the reduction of retention time of feeds in the large intestine resulting from the limitation of abdominal space by the foetus (Miraglia *et al.*, 1992).

The influence of work on digestibility of diets is still controversial because the published experimental data is contradictory. Using the most reliable experiments light and moderate work does not affect digestibility of hay-based diets supplemented with no more than 60% concentrate and fed 2 times maintenance feeding level (2.0 to 2.5 kg/100 kg BW). As a result there is no need to correct digestibility of forage and diet to calculate feed allowances.

12.1.2.8 Conclusions about the influence of factors of variation

The digestibility value of feeds, namely forages, displayed in tables of Chapter 16 that have been measured in light horses fed at maintenance can be used without any correction in respect to diet composition (proportion of concentrate) or linked to physiologic status (work, lactation and growth). However, effects on digestibility have been taken into account in pregnant mares by increasing the recommended feed allowances that are proposed in Chapter 3 using experimental data obtained at INRA in long term feeding trials. Hence, the end user has no need of recalculation.

12.1.3 The net energy value of feeds: UFC

The net energy value of feed is calculated from gross energy content (GE), digestibility of energy (dE), the ratio between metabolisable energy (ME) and digestible energy (DE) (ME/DE) and the energy efficiency of metabolisable energy for maintenance (K_m):

$NE = GE \times dE \times (ME/DE) \times K_m$.

Net energy value can be evaluated according to two methods regarding the expected accuracy and the end user's knowledge.

12.1.3.1 Forages and concentrates (ingredients): analytical method

This is the reference method used by INRA to calculate the energy value of feeds listed in the tables. This approach requires knowledge of the UFC system whose fundamentals are given in Chapter 1 (Figure 1.9). It consists of a step-wise procedure using at each step the relationship between energy value and chemical composition of feeds.

Gross energy

Gross energy (GE) is measured in the laboratory using a calorimeter. It is expressed in kilocalories/kg of dry matter (kcal/kg DM). It can be predicted from chemical composition using different models or equations, which change according to the feeds:
- The forages: gross energy content can be predicted from crude protein using the equations that are specific to each class of forage (Table 12.15);
- The concentrates (ingredients): gross energy value is predicted using an equation designed by INRA-AFZ (Sauvant *et al.*, 2004; Table 12.15 and 12.16).

Digestible energy

Digestible energy (DE) is calculated from GE and dE of feeds experimentally measured in horses:
$DE = GE \times dE$

Where:
DE = digestible energy (kcal/kg DM);
GE = gross energy (kcal/kg DM);
dE = digestibility of energy (%).

For laboratories dE can be predicted from OMd, when it is known:
$dE = 0.0340 + \Delta + 0.9477\ dOM$

where:
dE = digestibility of energy (%);
dOM = digestibility of organic matter (%);
$\Delta = +1.1$ for concentrates;
$\Delta = -1.1$ for forages.

Table 12.15. Equations used to predict gross energy value (GE) of feeds from their components (g/kg OM) (INRA, 2007; Sauvant *et al*., 2004).[1]

Category of feeds	n	Equations	RSD[2]	R^2
Green forages and hays			±38	0.89
Grasses	166	GEø = 4,531 + 1.735 CPø + Δ		
Grasslands		Δ = -71 green grasses		
Legumes and immature cereals		Δ = -11 green forages of red clover, sainfoin, mountainous grasslands, hays of seeded grasses, green immature cereals		
		Δ = +82 green forages of Lucerne and of low grasslands, hays of low and mountainous grasslands		
Green forages				
Sorghum	8	GEø = 4,478 + 1.265 CPø	±37	0.81
Maize[3]	59	GEø = 4,487 + 2.019 CPø	±25	0.33
Grass silages				
Pre-wilted		GEø = 1.03 × GEø green		
Haylage		GEø = GEø green		
Maize silages		GEø = 1.02 × GEø green if DM <30%		
		GE = GE green + 25 if DM >30%		
Dehydrated lucerne	27	GEø = 4,618 + 2.051 CPø	±64	0.41
Ingredients[4]	>2,000	GE = 4,134 + 1.473 CP + 5.239 CF + 0.925 CF – 4.46 ASH + Δ[b]		
Compound feeds	83	GE = 5.7 CP + 9.57 CF + 4.24 (OM – CP – CF)	±67	0.83

[1] For forages: GE Kcal/kg OM, e.g. GEø; for ingredients: GE kcal/kg DM; for compound feeds: GE kcal/kg OM, e.g. GEø.

[2] RSD = residual standard deviation.

[3] Equation is also applicable for dehydrated whole maize plants.

[4] In this equation, values are expressed in g/kg DM. For the values Δ (kcal/kg MS) per group of raw materials, refer to Table 12.16.

Example 12.1

dE = 55.8%, when dOM = 60% for forages.

For laboratories, OMd is predicted from the chemical composition or determined by the laboratories using equations or methods designed by INRA:

- Prediction of OMd from chemical composition of feeds assayed by the laboratories for forages (Table 12.5 and 12.9) and for ingredients (Table 12.6).
- Prediction of OMd by assaying the degradability of dry matter or organic matter by the laboratories using the pepsin cellulose method.

For the forages (Table 12.10):

$$dOM = -29.38 + \Delta + 2.30315\ dCell\ DM - 0.01384\ dCell\ DM^2 \qquad RSD=1.90;\ R^2=0.927;\ n=52$$

Table 12.16. Values of coefficient Δ (cal) to be used for predicting gross energy of ingredients (Sauvant *et al.*, 2004).

Feed material group	Δ
Corn gluten meal	308
Lucerne protein concentrate	248
Wheat distillery by-product, wheat gluten feed, maize bran, rice bran	138
Full fat rapeseed, full fat linseed meal, full fat cottonseed meal, cotton seed meal	116
Oats, wheat millings products, corn gluten feed and other maize starch by-products, maize feed flour, sorghum	75
Dehydrated grass, straw	46
Barley	36
Barley rootlets	-43
Linseed meal, palm kernel meal, full fat soybean meal, sunflower meal, sunflower seed	-46
Cassava	-55
Faba bean, lupin, peas	-87
Sugar beet pulp, molasses, potato pulp	-103
Whey	-177
Soybean hulls	-231
Other feed materials except starch and brewer's grains	0

where:
dOM = digestibility of organic matter (%);
dCell DM = degradability cellulase of dry matter (%);
Δ = +4.12 for green forages of grasslands (and silages);
Δ = 0 for hays of grasslands and seeded grasses;
Δ = -2.61 for lucerne hays.

Example 12.2

dOM = 63.1%, when dCell DM = 60% for green forage of grasslands.

For the concentrates (Table 12.14):

dOM = 0.6837 dCell OM + 19.447   RSD = ±5.6; R^2=0.560; n=17

Where:

dOM = digestibility of organic matter (%);
dCell OM = cellulase degradability of organic matter (%).

Example 12.3

dOM = 83.7%, when dCell OM = 93.9% for ground corn.

Metabolisable energy

Metabolisable energy (ME) is the potential value of feeds. Metabolisable energy content is predicted from digestible energy (DE) content and the ratio ME/DE:

$$ME = DE \times (ME/DE)$$

Where:
ME = metabolisable energy (kcal/kg DM);
DE = digestible energy (kcal/kg DM);
ME/DE = ratio which takes into account urine and methane energy losses.

For all feeds (except protein rich feeds and beet pulp):

$$ME/DE = 84.07 + 0.0165\ CF - 0.0276\ CP + 0.0184\ CC \quad RSD=1.37;\ R^2=0.45;\ n=79$$

Where:
ME/DE = expressed in %;
CF = crude fibre;
CP = crude protein;
CC = cytoplasmic carbohydrates (all expressed in g/kg DM).

Example 12.4

ME = 86.6% for grassland hay with CF=295 g/kg DM; CP=127 g/kg DM and CC=60 g/kg DM.

For protein rich feeds:

$$ME/DE = 94.36 - 0.0110\ CF - 0.0275\ CP$$

Meaning and expression of the symbols are the same as given previously for all feeds.

For beet pulp:

$$ME/DE = 89\%$$

As a reference the value of the ratio ME/DE varies according to the feed classes:

- oils meals: 78-80%;
- forages: 84-88%;
- straws: 90-91%;
- cereals: 90-95%.

In the case of grass silage, EM value should be corrected, because a proportion (15%) of digestible crude protein included is in non-amino acid form (ammonia, urea) and is not used as an energy source:

ME corrected = ME – (CP × 4.2 × 0.15)

Where:
ME = metabolisable energy (kcal/kg DM);
CP = crude protein (g/kg DM);

4.2 is a coefficient expressed in kcal/g DCP corresponding to the amount of metabolisable energy per gram of DCP that is not used as energy source.

Net energy

The net energy (NE) is calculated from metabolisable energy (ME) and efficiency of energy use (K_m):

NE = ME × km or km_c

Where km is used for concentrates and km_c for forages (excluding pelleted dehydrated forages) after correction (C) for energy cost of ingestion. The efficiency of energy utilisation can be predicted using the set of equations established by feed classes (Table 12.17).

But the efficiency of energy utilisation (K_m) is corrected for forages for the energy cost of ingestion using the cell wall content (crude fibre):

Δkm = -0.20 CF + 2.50

Where CF is expressed in % DM. The correction Δ is then applied to km previously calculated:

$km_c = km - \Delta km$

Horse Feed Unit value

Net energy value expressed in horse feed unit (UFC) is calculated from the net energy value (NE, kcal/kg DM) of the feed under consideration and the net energy value (NE, kcal/kg DM) of the reference feed barley (87% DM):

$$UFC = \frac{\text{NE feed: kcal/kg DM}}{\text{NE barley: 2,250 kcal/kg DM}}$$

Table 12.17. Prediction of energy efficiency (km) from chemical composition of feeds (Vermorel and Martin-Rosset, 1997).[1]

Feed	n	Equations	RSD	R^2
Forages	47	100 km = 71.64 – 0.0289 CF + 0.0148 CP	±0.94	0.878
		100 km = 65.21 – 0.0178 CF + 0.0181 CP + 0.0452 CC	±0.53	0.963
		100 km = 57.56 – 0.0110 CF + 0.0105 CP + 0.0270 CC + 0.0150 DOM	±0.40	0.980
Cereal and legume seeds	22	100 km = 82.27 – 0.0248 CF – 0.0160 CP	±0.66	0.962
		100 km = 72.34 + 0.0119 CF – 0.0081 CP + 0.0112 CC	±0.35	0.990
		100 km = 93.18 – 0.0490 CF – 0.0101 CP – 0.0127 DOM	±0.59	0.971
		100 km = 77.45 – 0.0060 MAT + 0.0106 MAT – 0.0054 DOM	±0.32	0.992
Cereal grain by-products	18	100 km = 100.32 – 0.0194 OM – 0.0120 CP – 0.0530 CF	±0.76	0.887
		100 km = 94.41 – 0.0237 OM – 0.0022 CP + 0.0121 CC	±0.45	0.961
Oil and legume meals	8	100 km = 67.13 + 0.00278 CF + 0.00528 CP	±0.44	0.700
		100 km = 67.03 + 0.00426 CP + 0.01566 CC	±0.29	0.900

[1] CC = cytoplasmic carbohydrates (g/kg DM); CF = crude fibre (g/kg DM); CP = crude protein (g/kg DM); OM = organic matter (g/kg DM); DOM = digestible organic matter (g/kg DM); RSD = residual standard deviation.

Example 12.5

Calculation of the net energy value (UFC) of a grassland hay harvested in Normandy: 1st cycle – early heading on 25th May (code FF0060 in tables).

GE = 4,418 kcal/kg DM
DE = GE × dE
dOM = 62%
dE (%) = 0.0340 + Δ + 0.9477 dOM   Δ = -1.1
dE= 57.7%
DE = 4,418 × 0.577 = 2,549 kcal/kg DM

$$ME = DE \times \frac{ME}{DE}$$

$$\frac{ME}{DE} (\%) = 84.07 + 0.0165\ CF - 0.0276\ CP + 0.0184\ CC = 86.5\%$$

CF = 295 g/kg DM   CP = 127 g/kg DM   CC = 60 g/kg DM

$$\frac{EM}{ED} = 86,\ 5\ p.\ 100$$

ME = 2,549 × 0.865   ME = 2,205 kcal/kg DM
km = 57.56 – 0.0110 CF + 0.0105 CP + 0.0270 CC + 0.0150 DOM
DOM = OM × dOM
DOM = 910 × 0.62
DOM = 564 g/kg DM

km = 65.7
Δ km = -0.20 CF (%) + 2.50 CF = 29.5%
Δ km = -3.4
km_c = km – Δ km
km_c = 65.7 – 3.4 = 62.3
NE = ME × km_c
NE = 2,205 × 0.623 NE = 1,374 kcal/kg DM

$$UFC = \frac{\text{NE forage}}{\text{NE barley}} = \frac{1{,}374 \text{ kcal/g DM}}{2{,}250 \text{ kcal/kg DM}} = 0.61 \qquad UFC = 0.61$$

The same step-wise approach should be implemented for the other categories of feeds.

12.1.3.2 Forages and concentrates (ingredients): direct method

The energy value of forages and ingredients can be directly predicted using equations calculated by INRA. Those equations relate the energy value expressed in UFC to the chemical composition (Table 12.18). The value that is calculated with the direct method is quite similar to that previously calculated, but slightly less accurate: ±0.01 to 0.02 UFC/kg DM.

12.1.3.3 Special case of processed cereal grains

The values which are listed in the tables correspond to cereals subjected to mechanical and thermal treatments. These values are confident and true as they include feed industry advances. The values give an idea of the relative impact of technological processes. For example corn grain, a grain that contains 24% starch that is difficult to digest (Chapter 9, Table 9.5) in the small intestine, compared

Table 12.18. Equations to predict directly the net energy value UFC (per kg DM) of forages and ingredients (Martin-Rosset *et al.*, 1994).[1]

Feed	n	Equations	RSD	R^2
Forages	47	UFC = 0.825 – 0.0011 CF + 0.0006 CP	±0.043	0.832
		UFC = 0.568 –0.0007 CF + 0.0007 CP + 0.0018 CC	±0.031	0.922
		UFC = -0.124 + 0.0003 CC + 0.0013 DOM	±0.012	0.988
		UFC = -0.0557 + 0.0006 CC + 0.2589 DE	±0.007	0.996
Ingredients	51	UFC = 0.815 – 0.0009 CF + 0.0003 CP + 0.0006 CC	±0.06	0.931
		UFC = 0.131 –0.0006 CF – 0.0003 CP + 0.00134 DOM	±0.041	0.967
		UFC = -0.730 – 0.0007 CP + 0.00057 OM + 0.3944 DE	±0.033	0.979
		UFC = -0.134 + 0.0003 CF – 0.0004 CP + 0.0003 CC + 0.3160 DE	±0.017	0.995

[1] CC = cytoplasmic carbohydrates (g/kg DM); CF = crude fibre (g/kg DM); CP = crude protein (g/kg DM); OM = organic matter (g/kg DM); DE = digestible energy (kcal/kg DM); DOM = digestible organic matter (g/kg DM).

to 13 to 17% in barley and wheat, respectively. The result is a difference of 20% in the proportion of energy supplied in the form of glucose from starch digestion in the small intestine, which leads to only 3% variation in net energy value: 0.04/1.30 UFC/kg DM. The result is similar for wheat bran. The 20% reduction in glucose supplied during digestion of starch in the small intestine only decreases the net energy value by 1.1 to 2.4%, e.g. 0.01 UFC/0.817 UFC/kg DM and 0.02 UFC/0.817 UFC/kg DM for coarse and fine wheat bran, respectively.

In addition, the proposed energy values are robust in the following conditions: variation of feeding level from 1 at maintenance to 2, the proportion of concentrates in diet ranging from 0 to 60%, which represent the majority of practical situations encountered, and when concentrates are fed after forages at each meal.

12.1.3.4 The compound feeds

Additive method

The UFC content is first calculated for each ingredient included in the compound feed formulation according to the previously described methods. Then, the UFC value is calculated by adding the amount of UFC of each ingredient weighted by its proportion in the compound feed composition. This approach is only usable by the person in charge of the feed formulation, because the proportion of ingredients in the composition of the compound feed must be known.

From the chemical composition and digestible components

The energy value can be directly predicted from the chemical composition and some digestible components with equations calculated by INRA using the weighted composition (types and proportions of ingredients used in compound feeds formulation) and the chemical composition of ingredients and compound feeds in a range of compound feeds confidentially supplied feed industry (Table 12.19).

These equations are very useful because the formulation of compound feeds is confidential. The proportion of ingredients and the technological treatments used are a processing secret. However, the feed company should provide a minimum of information: the chemical composition and energy value (Chapter 9).

12.1.4 The protein value of feeds: MADC

The protein value of feeds is expressed in digestible crude protein (DCP) that is corrected for the fraction of crude protein which does not supply amino acids in horses. As a result it is expressed in crude protein that is digestible in horses or MADC (e.g. horse digestible crude protein) (Chapter 1, Section 1.4.4). The MADC content results from the DCP content multiplied by a correction factor k linked to the type of feed (Table 12.20):

$$MADC = DCP \times k$$

Table 12.19. Equations to directly predict the net energy value UFCø (per kg OM) of compound feeds from the chemical composition and the content of some digestible components (Martin-Rosset *et al.*, 1994).[1]

Equations[2]	RSD	R^2
UFCø = 1.326 – 1.937 CFø – 0.135 CPø	±0.06	0.956
UFCø = 1.333 – 1.684 ADFø – 0.096 CPø	±0.06	0.958
UFCø = 1.173 –1.605 CFø + 0.051 CPø + 0.215 STAø	±0.04	0.976
UFCø = 1.181 – 1.397 ADFø + 0.082 CPø + 0.214 STAø	±0.04	0.978
UFCø = 1.219 – 0.852 ADFø – 0.287 NDFø – 0.857 Liø + 0.034 CPø + 0.207 STAø	±0.03	0.988

[1] ADF = acid detergent fibre (g/kg OM); CF = crude fibre (g/kg OM); CP = crude protein (g/kg OM); DOM = digestible organic matter (g/kg DM); Li = lignin (g/kg OM); NDF = neutral detergent fibre (g/kg OM); OM = organic matter (g/kg OM); RSD = residual standard deviation; STA = starch (g/kg OM); UFCø = horse feed unit/kg OM.

[2] +0.02 UFC point of crude fat over 3.5% crude fat/kg OM should be added to the final result calculated using the equations.

Table 12.20. Value of the correction coefficient k of digestible crude protein (DCP) to calculate the horse digestible crude protein (MADC) (Macheboeuf *et al.*, 1995, 1996; Martin-Rosset *et al.*, 2012b; unpublished data).

Forages	
k=0.90	green forages, haylages, maize silages
k=0.85	hays, dehydrated forages
k=0.70	pre-wilted grass silages correctly preserved
k=0.60	straws and by-products rich lignin
Ingredients	
k=0.87	native cereals grains
k=0.92	processed cereals grains and their by-products
k=0.94	legumes seeds and meals
k=0.85	dehydrated lucernes
k=0.70	dehydrated beet
k=0.60	soya hulls, by-products rich lignin

The values of the k coefficient are drawn from long term digestion experiments carried out by INRA during 1990-2010 (Chapter 1, Table 1.10 and 1.12).

12.1.4.1 Forages and ingredients

Digestible crude protein content can be predicted using equations, which relate DCP to CP content for forages (Table 12.7) and for ingredients (Table 12.8). The value of the coefficient K to be used to calculate MADC depends on the type of feed (Table 12.20).

Analytical method

The DCP content for forages is calculated from CP content and the digestibility of crude protein (dN) when it is known:

g DCP/kg DM = g CP/kg DM × dN

otherwise DCP is predicted using the equations displayed in Table 12.7. The MADC content is calculated using the relevant k coefficient appropriate to the considered forage (Table 12.20):

g MADC/kg DM = g MAD/kg DM × k

Example 12.6

Calculation of the protein value of a grassland hay harvested in Normandy: 1st cycle – early heading on 25th May (code FF0060 in tables) using the equation of Table 12.7.

CP = 127 g/kg DM
DCP = -25.96 + 0.8357 CP
DCP = 80 g/kg DM
MADC = DCP × k   k = 0.85
MADC = 80 × 0.85
MADC= 68 g/kg DM

The DCP content of ingredients is calculated from CP content and the digestibility of crude protein (dN) when it is known:

g DCP/kg DM = g CP/kg DM × dN

otherwise DCP is predicted using the equations displayed in Table 12.8. The MADC content is calculated using the relevant k coefficient appropriate to the considered ingredient (Table 12.20):

g MADC/kg DM = g MAD/kg DM × k

Example 12.7

Calculation of the protein value of an ingredient: barley (code CC 0010 in tables) using both the equation of Table 12.8 and the digestibility of crude protein.

CP = 116 g/kg DM
DCP = -2.68 + 0.833 CP
DCP = 116 × 0.81
DCP = 94 g/kg DM

MADC = DCP × k   k = 0.87
MADC = 94 × 0.87
MADC = 82 g/kg DM

Direct method

The protein value of forages (Table 12.21) and ingredients (Table 12.22) can be directly predicted using equations designed by INRA. These equations relate protein value expressed in g MADC to chemical composition. This value is quite similar to that calculated previously though a little less precise.

12.1.4.2 Compound feeds

Additive method

The DCP and then MADC content is first calculated for each ingredient included in the compound feed formulation according to the same described previously. Then the MADC value is calculated by adding the amount of MADC of each ingredient weighted by its proportion in the compound feed composition. This approach is only usable by the person in charge of the feed formulation because the proportion of ingredients in the composition of the compound feed must be known.

Table 12.21. Equations to directly predict protein value (g MADC/kg DM) of forages (Martin-Rosset, 2012).[1]

Forages	Equations	RSD	R^2
Green forages: grassland, grasses	MADC = -67.1 + 0.861 CP + 0.105 CF	±5.4	0.962
Pre-wilted silages (grasslands)	MADC = -23.0 + 0.816 CP – 0.058 CF	±7.2	0.894
Haylages (grasslands)	MADC = -52.0 + 0.683 CP + 0.132 CB	±6.1	0.845
Hays	MADC = -35.3 + 0.748 CP + 0.0316 CF	±7.7	0.897

[1] CF = crude fibre (g/kg DM); CP = crude protein (g/kg DM); MADC = horse digestible crude protein (g/kg DM); RSD = residual standard deviation.

Table 12.22. Equations to directly predict protein value (g MADC/kg DM) of ingredients (Martin-Rosset, 2012).[1]

Ingredients	n	Equations	RSD	R^2
Cereals grains	10	MADC = -4.50 + 0.738 CP	±5.4	0.951
Cereals by-products	19	MADC = -8.52 + 0.859 CP – 0.227 CF	±6.4	0.955
Legumes and oils seeds	10	MADC = -2.32 + 0.804 CP – 0.0719 CF	±4.3	0.976
Legumes and oils meals	13	MADC = -27.3 + 0.894 CP – 0.145 CF	±3.9	0.978
Dehydrated grasses and lucerne	8	MADC = -23.3 + 0.725 CP	±4.7	0.993

[1] CF = crude fibre (g/kg DM); CP = crude protein (g/kg DM); MADC = horse digestible crude protein (g/kg DM); RSD = residual standard deviation.

Direct method

The protein value is predicted directly from the chemical composition of the compound feed determined by routine laboratory analysis using equations calculated by INRA and using the weighted composition (types and proportions of ingredients used to formulate the compound feeds). The chemical composition of ingredients and compound feeds of a range of compound feeds that were confidentially supplied by the feed industry (Table 12.23).

12.2 Minerals components and their determination

12.2.1 Minerals

The content of the major minerals in the previous tables (INRA, 1990) has been revised by INRA (INRA, 2007). For forages, the contents have decreased to take into account the changes in the methods of production and of productivity during the last two decades. For concentrates, the contents have changed as well, because they come from the synthesis of several hundred determinations carried out for each ingredient by the French Association of Animal Science (Association Française de Zootechnie: AFZ in French) and INRA (Chapter 16).

12.2.1.1 Calcium

Calcium content is high in legumes, cruciferous plants and beet pulp. In contrast, calcium content is low in cereal grains, and maize silage (in the insoluble storage form). The content is lower in grasses than in legumes. The content decreases during the 1st vegetation cycle of forages and then increases during the following cycles. The content is reduced by haymaking and ensiling (Table 12.24).

The digestibility of calcium ranges between 55 to 75%. It increases with calcium content of the ration. It is higher in forages than in concentrates. It is higher in legumes than in grasses as well. For legumes, digestibility is not influenced if the ratio calcium/oxalate is higher than 0.5. The digestibility of calcium is not influenced by the type of soil. In contrast, the digestibility decreases if phytic phosphorus content is high because the calcium and phosphorus complex that is formed prevents the absorption of calcium.

Table 12.23. Equations to predict directly the protein value (g MADC/kg OM) of compound feeds (Martin-Rosset, 2012).[1]

Equations	RSD	R^2
MADCø = -28.8 + 0.850 CPø	±9.1	0.967
MADCø = -12.9 + 0.847 CPø – 0.109 CFø	±7.2	0.984
MADCø = -9.74 + 0.844 CPø – 0.0120 NDFø – 0.103 ADFø + 0.0923 ADLø	±3.4	0.985

[1] ADF = acid detergent fibre (g/kg OM); ADL = lignin content (g/kg OM); CF = crude fibre (g/kg OM); CP = crude protein (g/kg OM); NDF = neutral detergent fibre (g/kg OM); OM = organic matter (g/kg/DM); RSD = residual standard deviation; UFCø = horse feed unit/kg OM.

Table 12.24. Calcium and phosphorus content of feeds (INRA, 2007; Sauvant *et al*., 2004).

	Mean	Standard deviation	Minimum	Maximum
Forages				
Calcium (g/kg DM)				
Grasses	4.7	1.0	2.4	7.1
Legumes	14.0	2.7	8.8	18.5
Grasslands	6.0	1.6	3.5	11.8
Ensiled maize	2.0	0.5	1.0	5.0
Phosphorus (g/kg DM)				
Grasses	3.0	0.6	2.0	5.1
Legumes	2.7	0.4	2.0	3.7
Grasslands	3.0	0.9	1.2	4.1
Ensiled maize	1.8	0.3	0.5	4.9
Concentrates: ingredients				
Calcium (g/kg DM)				
Cereals grains	0.2	0.2	0.01	0.6
Cereals by-products	1.7	3.9	0.1	18
Cakes	0.6	0.8	0.01	2.8
Various by-products	3.1	8.3	0.1	14.7
Phosphorus (g/kg DM)				
Cereals grains	6	3.5	3.7	17
Cereals by-products	9	4.2	1	15
Cakes	15	5	7	24
Various by-products	15	14	3	52

12.2.1.2 Phosphorus

Phosphorus content is high in cereal grains and their by-products as well as in oilseed cakes. It is low in beet pulp, ensiled maize and late harvested forages. But the content is quite variable (Table 12.24). It decreases during the 1st vegetation cycle and then increases during the following cycles. It is reduced as well by haymaking and ensiling.

Digestibility of phosphorus ranges between 35 to 55% when phytic phosphorus content is low. Phytic phosphorus is an inositol hexaphosphate. Digestibility is reduced about two times when phytic phosphorus content rises, particularly in cereal grains and to a lesser extent in legumes seeds and cakes. As a result supplementation should be implemented with high quality phosphorus salts having a citric extraction rate higher than 85%. The digestibility of phosphorus rises with phosphorus and calcium content of the ration. In contrast, it decreases if the calcium content rises especially when the Ca/P ration is higher than 3-4. Digestibility of phosphorus does not seem to be influenced by magnesium content.

12.2.1.3 Magnesium

Magnesium content is generally higher in legumes than in grasses. It decreases during the 1st vegetation cycle and increases during the following cycles. In contrast, it is not influenced by the methods of preserving forages. The content is low in cereals grains but very high in cakes. It is intermediate in their by-products. The content is quite variable (Table 12.25).

The digestibility of magnesium ranges between 40 to 60%, mainly due to differences in feeds. The variation in digestibility with magnesium content and/or content of the ration is controversial. Digestibility is higher in forages, namely legumes, than in concentrates. It is higher for inorganic sources than for organic sources in plants. But there is no difference between inorganic sources of magnesium. There is also no influence of calcium oxalate. In contrast, digestibility decreases with the elevation of potassium and phosphorus content.

12.2.1.4 Sodium

The sodium content is very low in the majority of plants: forages or concentrates (Table 12.26 and 12.27). It decreases in forages during the 1st vegetation cycle. It does not change with haymaking but it decreases by 15% in silages. Digestibility of sodium ranges between 75 to 94%.

12.2.1.5 Potassium and chlorine

Potassium content is very high, whereas chlorine is much more moderate in forages (Table 12.26). Potassium is adequate in concentrates, whereas it is low for chlorine (Table 12.27). The contents are however, very variable whatever the feeds. The digestibility of potassium ranges between 61 to 65% while it reaches 100% for chlorine.

Table 12.25. Magnesium content (g/kg DM) of feeds (INRA, 2007; Sauvant *et al.*, 2004).

	Mean	Standard deviation	Minimum	Maximum
Green forages				
Grasses	1.6	0.2	1.2	2.0
Legumes	2.6	0.7	1.5	3.5
Grasses	2.3	0.3	1.9	3.1
Ensiled maize	1.2	0.3	0.1	5.0
Concentrates: ingredients				
Cereals grains	1.3	0.2	1.0	1.6
Cereals by-products	2.5	1.2	0.4	4.8
Cakes	4.3	1.6	0.7	6.6
Various by-products	1.6	1.0	0.5	4.5

Table 12.26. Sodium, potassium, and chlorine content (g/kg DM) of the main categories of forages (INRA, 2007).

	Mean	Standard deviation	Minimum	Maximum
Sodium				
Grasses	0.5	0.3	0.2	1.6
Legumes	0.4	0.1	0.3	0.6
Grasslands	1.8	1.3	0.5	3.2
Ensiled maize	0.2	0.2	0.01	1.4
Potassium				
Grasses	25	5	15	35
Legumes	24	6	15	35
Grasslands	19	4	11	25
Ensiled maize	9	3	3	25
Chlorine				
Grasses	8.3	1.3	6.0	12.0
Legumes	4.8	0.6	4.0	6.0
Grasslands	6.4	1.7	4.2	8.4
Ensiled maize	2.9	1.2	0.4	11.0

Table 12.27. Sodium, potassium and chlorine content (g/kg DM) of the main categories of concentrates (Sauvant *et al.*, 2004).

	Mean	Standard deviation	Minimum	Maximum
Sodium				
Cereals grains	0.2	0.2	0.01	0.6
Cereals by-products	1.7	3.9	0.1	18
Cakes	0.6	0.8	0.01	2.8
Various by-products	3.1	8.3	0.1	14.7
Potassium				
Cereals grains	6	3,5	3.7	17
Cereals by-products	9	4,2	1	15
Cakes	15	5	7	24
Various by-products	15	14	3	52
Chlorine				
Cereals grains	0.9	0.1	0.1	1.5
Cereals by-products	1.7	1.9	0.3	6.8
Cakes	1.2	1.5	0.4	6.8
Various by-products	5.2	8.3	0.3	30.9

12.2.1.6 Summary

The minerals content of forages vary:
- on one hand with the plant (family, species and variety), its growth (development stage, number of vegetation cycle, year of exploitation, seeding date), its morphological composition (ratio leaf/stem);
- on the other hand with environment: climate, soil and fertilisation and exploitation conditions.

The mineral contents that are displayed in the tables are gross means. As a result, the effect of the digestibility of minerals is included in the evaluation of requirements of animals (Chapters 1 to 8 and 13).

Supplementation with minerals is always necessary, whatever the forage based diet to balance the ration and meet the animal requirements (Chapters 1 to 8 and 13). But it is recommended to not surpass the limits of recommended daily allowances (Chapter 2, Table 2.1 and 2.12) and give attention to the balance between minerals.

12.2.2 Microminerals

Knowledge about microminerals contents of feeds is limited, variable and old for forages (Chapter 16, Appendix 1). Micromineral contents of ingredients is more numerous. A synopsis has been developed for more than 200 ingredients and published by Sauvant *et al.* (2004). For all feeds content is indicative because it is highly related to soil, climate conditions and technological treatments during harvest and processing.

12.2.2.1 Copper

Copper content is low in forages and cereals grains (<10 mg/kg DM) as opposed to cereal by-products (10-15 mg/kg DM) and oilseed cakes (19-70 mg/kg DM). The content is very low in maize silage whereas it is very high in sugar cane molasses. Copper digestibility ranges between 24 and 48%. The discrepancies between inorganic and organic sources are controversial.

12.2.2.2 Cobalt

Legumes seeds (0.08 to 0.39 mg/kg DM) and cakes 0.11 to 0.49 mg/kg DM) are richer in cobalt than most forages, with the exception of dehydrated Lucerne (0.08 to 0.30 mg/kg DM). The influence of vegetation stage at harvest and preservation condition is not known.

12.2.2.3 Zinc

Zinc content of grasses and legume forages and cereal grains is limited (20 to 50 mg/kg DM) whereas it is higher in cakes and cereal by-products (53 to 103 mg/kg DM). The content of ensiled maize is limited (20 mg/kg DM). Digestibility of zinc is 20%, and the influence of inorganic vs organic source on the digestibility is controversial.

12.2.2.4 Manganese

Manganese content is higher in forages than in ingredients but very variable in both feeds: 25 to 150 mg/kg DM and 10 to 50 mg/kg DM respectively. The content is higher in grasses than in legumes. It is also higher in cereal by-products (100 to 130 mg/kg DM) than in cereal grains and cakes (9 to 54 mg/kg DM). The digestibility of manganese ranges between 10 to 28%. It does not change with manganese source.

12.2.2.5 Iron

Iron content is little studied in forages. In contrast, the content is high in cereal grains (37 to 182 mg/kg DM) and their by-products (137 to 164 mg/kg DM), and in cakes (200 to 370 mg/kg DM). The content is rather limited in legumes seeds (27 to 69 mg/kg DM). The iron utilisation is reduced when the diet contents of cobalt, zinc and manganese are above recommendations (Chapter 2, Table 2.1).

12.2.2.6 Selenium

Selenium content is very low in forages (<0.1 mg/kg DM). Legumes are a little bit richer than grasses. The content is highly influenced by soil content and their pH. Selenium is in the organic form in the plants: selenocystine, selenocysteine, selenomethionine. It is possible to enrich forage to be harvested by tightly controlled fertilising. Cereal by-products and cakes content (0.24 to 0.82 mg/kg DM) is higher than that of cereals and legumes seeds (0.10 to 0.20 mg/kg DM).

12.2.2.7 Iodine

Iodine content of forages ranges between 0.1 to 0.3 mg/kg DM and there is little discrepancy between grasses and legumes. It is limited in ensiled maize (0.1 mg/kg DM). The content is influenced by soils but the effect of method of harvest is not known. Cereals and their by-products contents are low (<0.2 mg/kg DM). It may be higher in cakes but very variable (0.2 to 1.2 mg/kg DM). The content is very high in beet pulp and molasses (1 to 2 mg/kg DM).

12.2.2.8 Summary

Microminerals content of forages varies with plants, environment and method of exploitation and utilisation similar to minerals. The contents listed in the tables (Chapter 16) are indicative means in respect of the influence of all these factors. It is useful to know at a minimum the usual content for the most conventional microminerals (Cu, Co, Zn) in the area under consideration.

The rations should be supplemented (including when grazing) for most microminerals to meet the animal requirements (Chapters 1 to 8 and 13). But supplementation should not exceed the recommended concentration (Chapter 1, Table 2.1). The balance between some microminerals may be of particular importance for certain animals (Chapter 2, Table 2.1 and 2.12).

12.3. Vitamins

12.3.1 Vitamin A

Vitamin A belongs to the retinoids group which have the biological activity of all transretinols. Retinol is not present in the natural form in feeds. It comes from transformation of carotenoids of plants. It is conventionally accepted that one international unit (UI) of vitamin A is equivalent to 0.300 µg of transretinols. The β carotene is the main source of vitamin A. It is transformed into retinyl palmitate or retinyl stearate in the small intestine and then stored in the liver. The importance of this conversion is related to the amount β carotene ingested. It is generally accepted that 1 mg of β carotene is equivalent to 400 UI of vitamin A.

Forages are rich in carotenes which are the precursors of vitamin A (Chapter 16, Appendix 2). The carotene content is lower than in harvested forages (Chapter 11, Figure 11.4). Industrial dehydration that is well managed preserves the largest proportion of carotenes content (for example Lucerne). Ensiling allows a satisfactory preservation as well. In contrast, haymaking, carried out in poor conditions, greatly reduces the carotene content because oxidative destruction occurs under long sunny conditions. The carotene content of cereal grains (but not yellow grain corn), their by-products and straws is low (Chapter 16, appendix 2). Maize silage, roots and tubers are also poor in carotenes.

The efficiency of synthetic β carotenes used in supplements as a source of provitamin A has not actually been established. Retinyl acetate and palmitate are the most frequently used forms of vitamin A in supplements because they are more stable than the retinol (none esterified) form. It is accepted that 1 UI of vitamin A is equivalent to the biological activity of 0.550 µg of trans-retinyl palmitate and of 0.344 µg of trans-retinyl acetate.

12.3.2 Vitamin D

Vitamin D is present in plants in the form of ergocalciferol, vitamin D3 and in animal in the form of cholecalciferol, vitamin D3. The content of feeds is generally low, but vitamin D is synthesised by skin under the effect of UV-rays in the form of 7-dehydrocholesterol.

Vitamin D content can be high in hays but it is very variable. The content is very low in green forages, silages and ingredients (Chapter 16, Appendix 2). Vitamin D3 is the most usual form for the supplementation.

12.3.3 Vitamin E

Vitamin E comes from eight natural compounds: 4 tocopherols (α, β, γ, δ) and 4 tocotrienols (α, β, γ, δ). These compounds consist of a chromanol circle and a lateral chain linked on carbon 16. This chain is saturated in tocopherols whereas it is unsaturated in tocotrienols. The biological activity of these various forms depends on the number and the location of methyl groups on the chromanol circle. Eight steroisomers exist. The natural isomer, so called RRR, is the one that has the highest biological activity (1.49 UI/mg).

Vitamin E content is generally high but very variable in green forages and early harvested forages (10 to 150 UI/kg DM). Content is low and very variable in ingredients (30 to 50 UI/kg DM).

12.3.4 Vitamin K

Vitamin K naturally exists in plants in the form of phyloquinone (K_1; 2-methyl-3-phytil-1,4-naphtoquinone). Green forages are rich sources (3 to 22 mg/kg DM) whereas cereals are poor (0.2 to 0.4 mg/kg DM). Digestive tract bacteria produce vitamin K in the form of quinine K_2; 2-methyl-1,4-naphtoquinones, but the contribution to requirements is unknown. The menadione form is used for supplementation. The effect of excess phyloquinone is unknown.

12.3.5 Vitamin B

Vitamins B are present in feed and synthesised in the digestive tract.

Thiamine (vitamin B1) content of ingredients is rather high (cereals grains: 3 to 6 mg/kg DM, their by-products: 8 to 23 mg/kg DM; cakes: 6 to 12 mg/kg DM). The forms used for supplementation are thiamine hydrochloride or thiamine mononitrate.

Legumes are rich in riboflavin (vitamin B2) (13 to 17 mg/kg DM) compared to grasses hays (7 to 10 mg/kg DM) and to cereal grains (2 mg/kg DM). The natural forms of riboflavin are flavin adenine dinucleotide (FAD) and flavin mono nucleotide (FMN). There is microbial synthesis in the large intestine.

Niacin (vitamin B3) is naturally present in feeds in two forms: nicotinic acid (pyridine-3-acide carboxylic) and nicotiamid (acid nicotinic amid) or NAD and NADP respectively. Cereal grains content is high (16 to 94 mg/kg DM) but 90% is unavailable. No allowance is stated. Forage content ranges between 24 to 42 mg/kg DM but under which form? Oil seeds content is high but only 40% is available. Soya cake contains about 30 mg/kg DM but the fraction available is unknown.

Biotin (vitamin B7) is an acid 2-keto-3-4-imidazilido-2-tetrahydiothiophinevaleric that exists under 8 isomer forms. Only the d-biotin form has a biological activity. Biotin is present in plants under of a form linked to a protein, for example biocytine: ε-N-biotynil-L-lysine. Its availability depends on the protein with which it is linked. Lucerne has a high content (0.49 mg/kg DM) but the content decreases significantly after haymaking (0.29 mg/kg DM). The content of cereal grains ranges between 0.11 to 0.50 mg/kg DM. The content is very low in maize grain (0.06 to 0.10 mg/kg DM).

Folate (folic acid, vitamin B9) is present in feeds. The content of lucerne and timothy hays range between 2.3 to 4.1 mg/kg DM. Cereals grains content is low (<0.6 mg/kg DM). Green forages probably have a higher content. Folic acid is synthesised by the microbial microflora of the large intestine. The availability of folic acid supplied in supplements would be low.

12.3.6 Vitamin C

Vitamin C is not found in feeds. Vitamin C exists under 2 forms: L-ascorbic acid and L-dehydro-ascorbic acid that have equivalent biological activity. The most efficient synthetic form for supplementation would be palmitate ascorbyl.

12.4 Feed intake: ingestibility concept

The feed intake of horse depends on factors linked to the feed and the animal. With respect to feeds, intake is generally higher for forages that are the basis of diets than for concentrates that are only fed as supplements in limited amounts.

Intake of forages is the most variable in respect to their specific characteristics. Water content can range from 85 to 15% in green grass at grazing stage and hay harvested in June-July, respectively. Water content of concentrates ranges between 10 to 20%. As a result intake is expressed in kilo of dry matter, the less variable parameter with which to compare feeds. Even using this parameter the amount of ingested forages varies greatly owing to their botanical and chemical characteristics, harvest condition and preservation, and the technological processes used. Hence each feed and especially forages are characterised by their ingestibility, which expresses the amount of feed that an animal can ingest spontaneously when this feed is fed free choice. The ingestibility is expressed in kilo of dry matter per 100 kg bodyweight (kg DM/100 kg BW). It has been measured for the principal forage classes (Table 12.28).

The ingestibility of forages ranges between 0.9 to 2.6 kg DM/100 kg BW. It is more limited in silages with low dry matter content, as a result they should be pre-wilted, and in straws owing to the very high cell wall content. Ingestibility of legumes is higher than that of grasses (10 to 15%).

Conversely to ruminants, crude fibre content limits slightly, the ingestibility of forages in horses except for straws (Figure 12.8). In contrast, the horse is very sensitive to organoleptic qualities especially of silages and haylages that are baled. The content and the volatile fatty acids composition and/or ammonia should represent a good preservation quality to not be limiting parameters (Chapter 11). There is, therefore, no feed intake system to evaluate and then predict intake in horses as there is in ruminants based on the physical regulation of intake (filling concept of digestive tract by forages so called feed unit system proposed by INRA 1978-2013). Intake regulation in horses is more complex than in ruminant (Chapter 1). The proposed intakes in tables of daily nutrient requirements (Chapter 3 to 8) are based on the measured intake capacity of horses in respect to the previously measured ingestibility of forages (see for example: Table 12.26).

The animal-factor interacts with the feed factor. Chapter 1 describes the inclusion of this interaction in diet formulation (Chapter 2 and 13). This leads to the expression of feed intake in kilos of dry matter per 100 kg of bodyweight in all the physiological situations. This is as important for forages as for concentrates. The substitution rate (Chapter 1) between these two categories of feeds must be taken into account for diet formulation in certain types of animals (mares, young horses; Chapter 3 and 5 especially).

Table 12.28. Ingestibility of principal forages in horses (Martin-Rosset and Doreau, 1984; Trillaud-Geyl and Martin-Rosset, 2005).

Feeds	Intake[1,2] (kg DM/100 kg bodyweight)
Green forages of grassland	1.8-2.1
Hays of grassland and grasses	1.7-2.1
Hays of legumes	2.1-2.3
Straws	1.2-1.5
Silage of maize well preserved	
-25% DM[3]	0.9-1.2
-30% DM	1.2-2.0
Silage of grass pre-wilted and well preserved (grassland)	
-25% DM	1.2-1.5
-35% DM	1.5-1.8
Haylage (grassland, grasses)	
-45% DM	2.2-2.4
-60% DM	2.4-2.6

[1] Maximum amount of forage ingested by the animal fed free choice.
[2] The range represents the variation between animals.
[3] DM = dry matter.

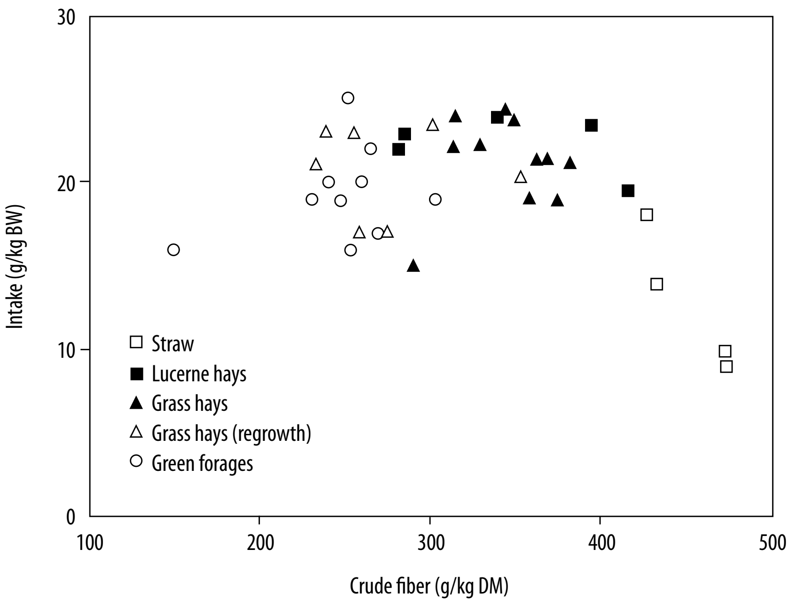

Figure 12.8. Variation in the ingestibility of forages with crude fibre content (Dulphy *et al.*, 1997b).

The feed intakes that are displayed in the tables of recommended daily allowances (Chapter 3 to 8) are given as ranges for each type of animal (Chapter 2 to 7) for a very fed large panel of forages (Table 12.28) and rations (Chapter 3 to 7) to allow the largest possible range of forage intakes in all these situations. These intakes have been measured using large number of animals in long term feeding trials inserted into the normal breeding or using cycle carried out at INRA between 1970 and 2010.

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Chapter 13. Formulating a ration

Luc Tavernier and William Martin-Rosset

There are different methods to formulate the composition of a diet and the amount of feed to meet the energy and protein allowances recommended for each type of animal displayed in the tables of Chapter 3 to 8.

Two of these methods are proposed and explained here:
- A graphical method
- An informatical method

The procedure to calculate mineral and vitamin supplementation is also described at the end of this chapter.

13.1 Methods of formulating a daily ration

13.1.1 The different methods and their common basis

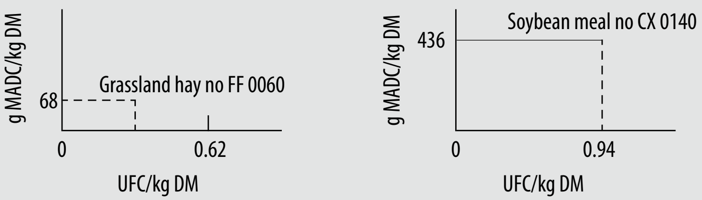
Two methods using a primary graphical representation:
- Of the main feeds available to feed the horse and then to improve their visualisation comparing with the list displayed in the tables of chemical composition and nutritive value of feeds (Chapter 16).
- Of the optimal ration to formulate and then to facilitate the choice of feeds to be included in the composition of diet.

13.1.2 Graphical representation of available feeds

All the feeds listed in the tables are characterised by their energy and protein value expressed in UFC and grams of MADC per kg of dry matter (DM). They can be graphically represented (Figure 13.1).

The richest feeds in energy (UFC/kg DM) and the richest feeds in protein (g MADC/kg DM) are easy to locate on the horizontal and vertical axis respectively. The most common feeds are displayed on the graph (Figure 13.1) using the numbers provided in the tables (Chapter 16).

Example 13.1. Graphs of grassland hay and soybean meal.



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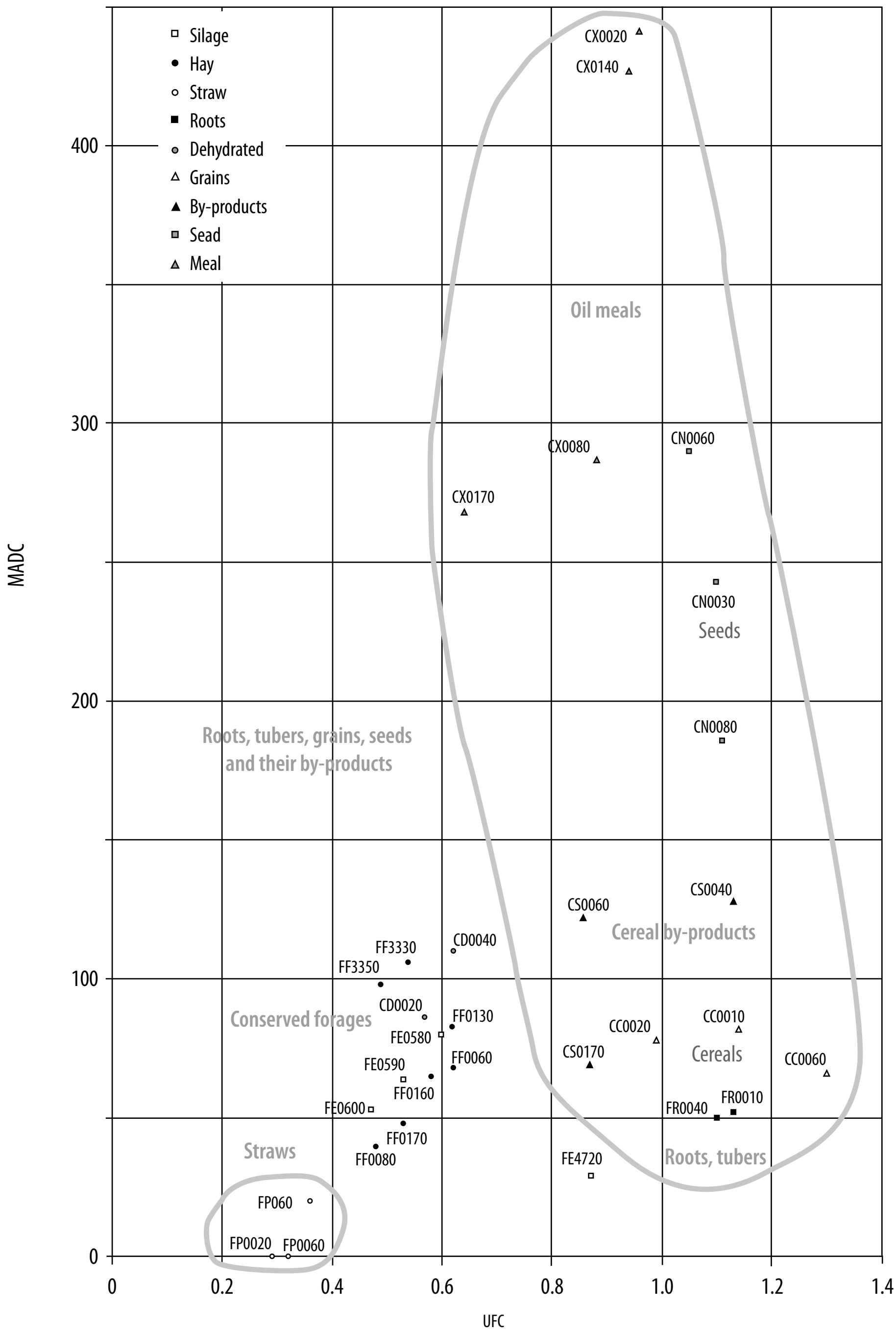


Figure 13.1. Graphical representation of the most common feeds.

13.1.3 Characteristics and representation of the optimal ration

The optimal daily ration is the one which supplies the amount of energy (X, UFC) and protein(Y, g MADC) corresponding to the daily total allowances recommended for that type of animal (Chapter 3 to 8) using the dry matter intake in the range given in the column entitled 'dry matter intake(kg)' of the corresponding table.

The highest dry matter intake of forages is chosen to feed the animal the highest limit of the range. In contrast, the lowest limit should be chosen if the forage intake is restricted. The nutritional content of one kilo of dry matter of this ration is:

For energy: $\frac{\text{X, UFC}}{\text{DM intake}}$ and for protein: $\frac{\text{Y grams MADC}}{\text{DM intake}}$

Example 13.2. Mare of light horse breed 500 kg BW, good body condition score, 1st month of lactation, box stalled on wheat straw bedding.

Recommended feed allowances (Chapter 3, Table 3.7)

Energy	Protein	Intake
8.5 UFC	956 g MADC	11.5-15.0 kg DM

Therefore the energy and protein content of 1 kg of dry matter of this ration for this mare is:

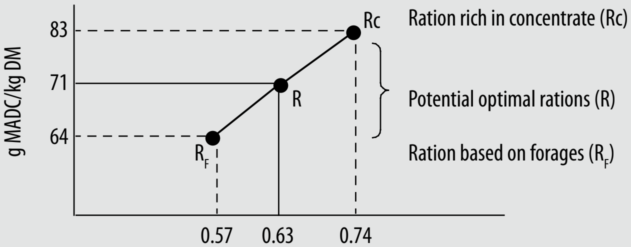
If large amounts of hay are fed

$\frac{8.5}{15.0}$ = 0.57 UFC/kg DM $\frac{956}{15.0}$ = 64 g MADC/kg DM

If the amount of hay is restricted

$\frac{8.5}{15.0}$ = 0.74 UFC/kg DM $\frac{956}{11.5}$ = 83 g MADC/kg DM

The optimal ration (R) can be represented on the same graph as the feeds using the characteristics (content) that have been previously calculated.



Between these two extreme limits RF and RC a large number of potential rations are possible according to the chosen feed intake. Hence, for an intermediate dry matter intake between 11.5 and 15.0 kg, for example 13.5 kg DM, the optimal ration is characterised by:

An energy content UFC/kg DM = $\frac{8.5}{13.5}$ = 0.63

A protein content: g MADC/kg DM = $\frac{956}{13.5}$ = 71 g

The proportion of forage of this intermediate ration will be higher than the ration RC but lower than the ration RF. C the proportion of concentrate would be the opposite.

13.1.4 Graphical method for calculating the daily ration

13.1.4.1 Case A: composition of an optimal ration composed of 1 or 2 feeds

Figure 13.1 is duplicated on a separate page in the appendix of the book according to a special format on a separate sheet supplied in appendix. This format of the figure should definitely be used to implement the graphical method. It makes the calculation easier and more accurate. The graphical values that are indicated in the following part of this chapter have been measured using this formatted sheet. It is suggested to photocopy this sheet or to download it from the following address: http://www.ifce.fr.

If the R point, located on the same graph as the feeds, coincides with a feed which is available (for example: grassland hay), it is only necessary to choose this feed and then to offer the corresponding amount on the graph (column: dry matter intake of tables, Chapter 3 to 8). In this situation, the ration is only balanced to meet UFC and MADC requirements with respect to the designated dry matter intake. However, the ration will have to be routinely balanced with mineral and vitamin feed supplement (MVFS) (see Section 13.2).

This feed will be accepted as the total ration if the UFC/kg DM and MADC/kg DM contents are no further far from 0.05 UFC and 5% g MADC than those of the ration. This fair situation is encountered if the nutritional requirements are very limited: horse at rest; late growth of three year old horse.

Example 13.3. Pregnant mare, 550 kg BW, 6th month of gestation.

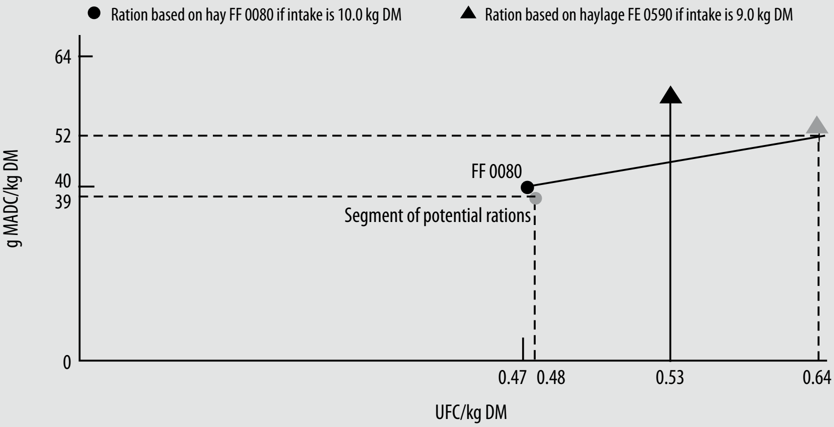
Recommended feed allowances (Chapter 3, Table 3.8):

Energy	Protein	Intake
4.8 UFC	387 g MADC	7.5 to 10.0 kg DM

The content of the optimal ration should range between

$\frac{4.8}{10.0}$ = 0.48 UFC/kg DM and $\frac{4.8}{7.5}$ = 0.64 UFC/kg DM

$$\frac{387}{10.0} = 39 \text{ g MADC/kg DM and } \frac{387}{7.5} = 52 \text{ g MADC/kg DM}$$



The nutritive value of hay FF 0080 is close to that of the optimal ration. Ten kg DM of this hay can be fed to meet MADC and UFC requirements. As a result, the ration supplies 10.0 × 0.47 UFC = 4.7 UFC and 10.0 × 40 = 400 g MADC. The ration is very well balanced with 0.00 UFC and +13 g MADC difference.

Grassland wrapped silage (e.g. haylage) FE 0590 could be suitable (0.53 UFC and 64 g MADC/kg DM). In this case: 4.8/0.53 = 9.0 kg DM of forage are necessary to meet the energy requirement, as a result the ration supplies: 9.0 × 64 = 576 g MADC, thus 189 g = 576 – 387 g in excess. This excess of MADC was predictable because the feed was located above the line of the potential R.

This example describes only one principle of the calculation, but it should not be implemented further without taking into account additional aspects of formulation. In this example neither the requirements for mineral, micromineral and vitamin are considered nor the quality of protein that is supplied, are included in the final calculation to balance the ration.

In most cases and mainly in productive horses, a ration including at least two feeds F (forage) and C (concentrate: supplemental feed) should be calculated. The choice of the feeds F and C and their proportion in the ration can be determined using the graph. The principle is to choose the forage (F) and the characteristics of the supplemental feed (C).

Example 13.4. Mare of light horse breed, 500 kg BW, average body condition score, 11th month of gestation.

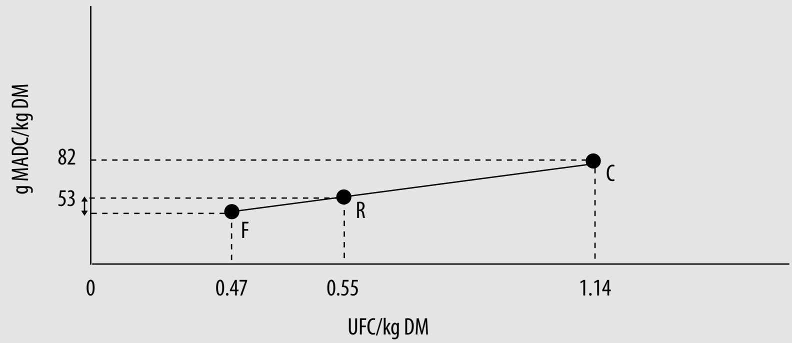
Recommended feed allowances (Chapter 3, Table 3.7):

Energy	Protein	Intake
5.5 UFC	530 g MADC	8.0-11.5 kg DM

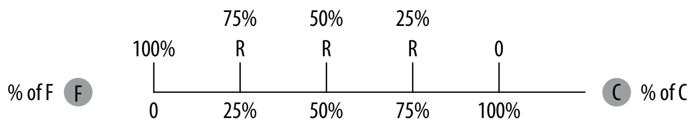
The contents of the optimal ration should be

$\frac{5.5}{10.0}$ =0.55 UFC $\frac{530}{10.0}$ = 53 g MADC/kg DM

If we assume that there is an important supply of forage and the dry matter intake is fixed to 10.0 kg.



R should definitely be on the segment between F and C in order to design a ration including two feeds. The highest is the percentage of the feed F in the ration, the closest or the most far away is the point R in regard to F or of C respectively.



In practice, the length of the two distances FR, RC should be measured in millimetre using a ruler. In fact, RC should be measured then FC:

- F and C: length (FC) or dFC;
- C and R: length (CR) or dCR.

The percentage of F in the ration is calculated using the following relationship:

$$\text{Percentage of F} = \frac{\text{length (CR)}}{\text{length (FC)}}$$

The amount of forage in the ration results from the multiplication of the total dry matter intake by the percentage of F in the ration. The amount of concentrate C comes from the subtraction of the amount of forage intake to the total dry matter intake.

Example 13.5. Mare of light horse breed, 500 kg BW, average body condition score, 11th month of gestation (see previous example).

dFC = 10.3 mm dCR = 8.9 $\% \text{ of } F = \frac{8.9}{10.3} = 0.864$ or 86.4%

Therefore, the optimal ration is composed of 86.4% of haylage FF 0600. The dry matter intake that is chosen is 10.0 kg, then the intake of haylage (code FE 0600, tables in Chapter 16) is: 10.0 × 0.864 = 8.64 kg DM and barley intake is: 10.0-8.64 = 1.36 kg MS.

Validation:

Ration	Ration supply	Daily recommended allowances
8.64 kg DM of haylage× 0.47 UFC/kg DM	4.06 UFC	
1.36 kg DM of barley × 1.14 UFC/kg DM	1.55 UFC	
Total	5.61 UFC per day	5.50 UFC
Therefore +0.11 UFC difference, which is acceptable.		
8.64 kg DM of haylage× 53 g MADC/kg DM	458 g MADC	
1.36 kg DM of barley × 82 g MADC/kg DM	112 g MADC	
Total	570 g MADC	530 g MADC

Therefore +40 g de MADC difference, which is acceptable.

The percentage of forage and concentrate that have been measured on the graph can be validated using the following univariate equation:

$$0.47\,F + 1.14\,C - 0.55 \times 100 \qquad (1)$$

Where:

F = percentage of forage in the ration;
C = percentage of concentrate in the ration;
0.47 = energy value (UFC) of haylage (code FE 0600);
1.14 = energy value (UFC) of barley (code CC 0010);
0.55 = energy value (UFC) of the designed optimal ration.

The percentage of concentrate (C) in the ration is:

$$C = 100 \text{ (total ration)} - F \qquad (2)$$

C is substituted in Equation (1) by Equation (2):

0.47 F + 1.14 (100 – F) = 0.55 × 100
0.47 F + 1.14 – 1.14 F = 55
F (0.47 – 1.14) = 55 – 1.14 – 0.67 F = -59

$$F = \frac{59}{0.67} = 88.1\%$$

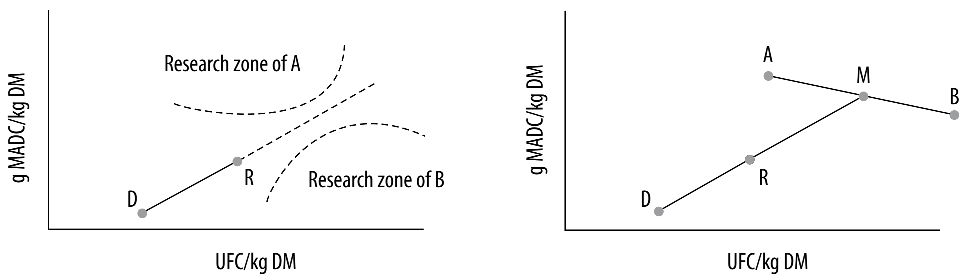
C = 100 – 88 = 12%

This simple algebraic calculation allows:
- To check that the calculation previously carried out using only the graph is correct with an accuracy of 1.7%, F = 88.1% instead of 86.4%.
- To point out that the optimal composition of the ration can be quickly designed using the graph and/or a simple algebraic calculation.

13.1.4.2 Case B: composition of an optimal ration composed of 3 feeds

The optimal ration is not always located on the segment between two available feeds. A ration could be composed with 3 feeds using the same previous principle and a step-wise procedure.

The primary feed (P) is the one that the user wants to prioritise in the ration (for example, the forage harvested for winter feeding, the cultivated cereal grain, or the by-products of the agriculture or feed industry). This feed is designated by the point P on the graph using the UFC/kg DM and g MADC/kg DM content.



The feed P is associated with the mixture (M) of two other feeds A and B of the ration. The mixture M of A and B should be located on the straight line PR, opposite to P, in order to compose with P the ration: P + M = R. The feeds A and B should be located on the opposite sides of this straight line so that the mixture M can be situated on the straight line PR.

The ration is designed from the feed P and the mixture M introduced in the ration (R) according to the percentages that have been calculated as mentioned below, after having measured the lengths MR and PM using a ruler.

$$\text{Percentage of P in R} = \frac{\text{length MR}}{\text{length PM}} \quad (1)$$

Thus, the amount of P in R is calculated by multiplying the result given previously (1) by the total dry matter intake chosen in the range displayed in the tables of recommended allowances. The amount of M in the ration results from this calculation.

When the feeds A and B have been determined, the percentage of the feed which is closer to M, A in our example, is calculated measuring the lengths BM and AB using a ruler.

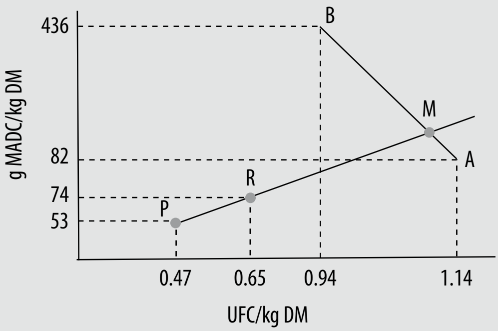
$$\text{Percentage of A in M} = \frac{\text{length BM}}{\text{length AB}} \quad (2)$$

By multiplying this percentage by the amount of mixture previously calculated, the amount of A is obtained and hence the amount of B by difference.

Example 13.6. Mare of light horse breed 500 kg BW, very good body condition score, 1st month of lactation, box stalled on wheat straw bedding.

Recommended feed allowances (Chapter 3, Table 3.7):

Energy	Protein	Intake
8.5 UFC	956 g MADC	11.5-15.0 kg DM



Assuming that an intermediate energy density of the ration is expected, 13.0 kg dry matter intake is chosen. The optimal ration should supply

$\frac{8.5}{13.0}$ = 0.65 UFC per kg DM $\frac{956}{13.0}$ = 74 g MADC per kg DM

Feed P can be a grassland haylage: 0.47 UFC and 53 g MADC/kg DM (no. FE 0600 in the tables of Chapter 16). Feed A can be barley (no CC 0010). Feed B can be soybean meal 48 (no CX 0140) to balance crude protein of the ration.

The lengths are measured:

MR = 72 mm PM = 100 mm
BM = 91 mm AB = 106 mm

We calculate:

- the percentage of P in R = $\frac{72}{100}$ = 0.72 or 72% (1)
- thus the amount of P is 0.72 × 13.0 kg DM = 9.36 kg DM
- therefore the amount of M is 13.0 – 9.36 = 3.64 kg DM
- the percentage of A in M = $\frac{91}{106}$ = 0.876 or 87.6% (2)

the percentage of A (or barley) in R = 0.876, hence the amount is 0.876 × 3.64= 3.19 kg DM of barley. Thus the amount of B (or soybean meal 48) in M is 3.64 – 3.19 = 0.45 kg DM of soybean meal.

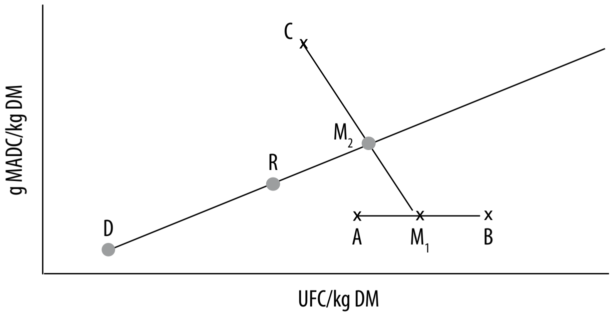
Verification (Table 13.1):

Ration	Allowances
9.36 kg DM of haylage × 0.47 UFC/kg DM	4.40 UFC
3.19 kg DM of barley × 1.14 UFC/kg DM	3.64 UFC
0.45 kg DM of soybean meal × 0.94 UFC/kg DM	0.42 UFC
Total	8.49 UFC per day for 8.5 UFC of recommended allowances
9.36 kg DM of haylage × 53 g MADC/kg DM	496 g MADC
3.19 kg DMS of barley × 82 g MADC/kg DM	262 g MADC
0.45 kg DM of soybean meal × 436 g MADC/kg MS	196 g MADC
Total	954 g MADC per day for 956 g MADC of recommended allowances

The algebraic method can verify again that the calculation is correct as in Example 13.5.

13.1.4.3 Case C: composition of an optimal ration composed with more than 3 feeds

The general procedure is generally the same as the one described previously. Following the choice of a primary feed, the straight line PR is drawn. Then the user can decide to offer a mixture of feeds A and B. The point M is located on the segment AB in regard to the respective percentages of A and B in M. Then a supplement C is chosen in the opposite position of M over the straight line PR. Assuming that the supplement feed should be C, the segment MC crosses the straight line PR in M_2. Two mixtures M_1 and M_2 are composed from 3 feeds A, B and C, which are complementary to feed P. Each mixture and their corresponding graphical point are subsequently considered as any feed from which we should refer along the procedure.

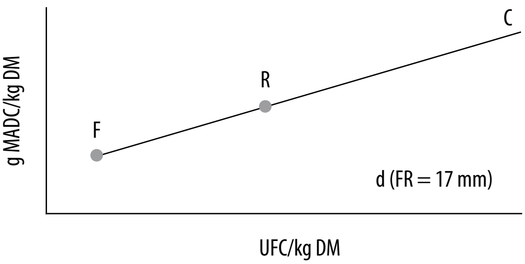


The length PM_2, and the longest length PR or PM_2 are measured. Thus the percentage of P or M_2 is established according to the chosen length. Hence, the respective amount of P and M_2 are calculated using this percentage. The amount of C and M_1 in M_2 then of A and B in M_1 are calculated using the same step-wise procedure.

13.1.4.4 Case D: ration with percentages of forage (F) and concentrate (C) fixed in advance

The nutritive value of the forage (F) is known or chosen at the start. The straight line FR can be drawn. The location of the point C is determined by dividing the length FR measured on the graph by the fixed percentage of the concentrate feed C in R.

$$FC = \frac{\text{length FR}}{\%C}$$



Example 13.7. Ration composed of 60% forage (F) and 40% concentrate feed (C).

dFR = 17 mm

Percentage of C in R = 0.40 (or 40%)

$$dFC = \frac{17}{0.40} = 43 \text{ mm}$$

The point C is located 43 mm away of F along the straight line FC passing through R.

If there is no simple concentrate feed close to C, a mixture should be composed from appropriate simple concentrate feeds, as described previously in examples B and C.

13.1.4.5 Case E: basal ration with percentages of two forages (F_1) and (F_2) fixed in advance

The forages F_1 and F_2 are chosen in advance and their percentages in the mixture of forages as well. The segment F_1-F_2 is drawn and the location of F is calculated:

Length F_2F = length $F_1F_2 \times$ percentage of F_1.

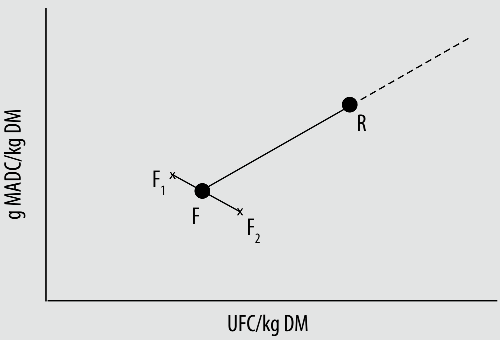
The straight line FR can be drawn and continued to determine and calculate the type and the proportion of concentrate respectively to be offered to balance the ration according to the procedure previously described.

Example 13.8. Ration composed with x % of forage (F) and y % of concentrate feed (C).

The ration is based on two forages. F_1 is hay whereas F_2 is straw in respective proportion fixed in advance 40% and 60% (or 0.4 and 0.6) respectively.

Length F_1F_2 = 10 mm

Length F_2F = 10 mm × 0.6 = 6 mm



13.1.5 Computing the calculation of the daily ration

Nutrient allowances, displayed in tables of Chapter 3 to 8, have been established using sets of equations designed by the INRA group in the research centre of Clermont/Theix, France. In the 2nd edition of this book (INRA, 1990), these kinds of equations were incorporated into a computer model which was commercialised as Chevalration©. However, there is evidence until today that the education of the end-users is too limited and too varied to design a new complex software even if safety keys are incorporated into the system to prevent all misunderstanding with the complex biology of horse. Indeed, there are so many variables that are involved in the understanding of inputs to be used and the outputs that are generated, which should be accurately interpreted. Commercial software programs have been designed by private companies at least in France. These software programs are not based on the equations supplied by INRA and INRA makes no claim about the accuracy of these tools. It is under the responsibility of both the companies and end-users.

So far, a new pedagogic strategy has been adapted using an MS Excel table especially designed by the two co-authors of this chapter assisted by a committee including advisors and end-users. This pedagogic tool is called 'Equinration' 2015. The end-users may be coached by advisor experts in the early stages of training during practice sessions given either at the College for animal science education (Rambouillet, France) or other sites across France, and then by assistance on-line: http://www.ifce.fr. In such way, the end-users are increasingly educated, getting the skills to implement the procedure and tools and establish contact with the expert-advisor.

13.1.6 Calculation of as fed materials to be offered

In the field the amount of feeds to be offered are expressed in kilogram of fresh materials. Hence these amounts are calculated as followed:

$$\text{Amount of feeds (kg fed)} = \frac{a}{b}$$

Where:

a = amount of feed expressed in kg dry matter;
b = percentage of dry matter of the feed listed in the tables of Chapter 16.

Example 13.9. Mare of light horse breeds 500 kg BW, very good body condition score, 1st month of lactation.

In respect of the calculation carried out previously: Example 13.6 in this chapter, the ration expressed in kg dry matter is composed of:

Feeds	Amount DM	DM content
Grassland haylage (no FE 0600)	9.36 kg DM	55% or 0.55
Barley (no CC 0010)	3.19 kg DM	87% or 0.87
Soybean meal 48 (no CX 0140)	0.45 kg DM	88% or 0.88

The as fed amount of forage to be offered is: $\frac{9.36}{0.55} = 17.0$ kg

The as fed amount of barley to be offered is: $\frac{3.19}{0.87} = 3.66$ kg

The as fed amount of soybean meal to be offered is: $\frac{0.45}{0.86} = 0.51$ kg

The ration expressed in as fed kg to be offered is thus composed of 17.0 kg grassland haylage, 3.66 kg barley and 0.51 kg soybean meal 48.

13.1.7 Verification of the calculation – formulation form

The main elements that are necessary to be used for calculating a ration and the resulting data should be incorporated in a formulation form (Table 13.1). This form allows for checking:

- if the diet composition is correct;
- if the total nutrient allowances of the ration equal the recommended allowances for energy (±0.05 UFC) and for protein (±5% maximum);
- or if they are different (most often lower) than the recommendations of minerals such calcium (Ca), phosphorus (P), to plane for mineral supplementation;
- regarding the microminerals, the ration should be balanced namely for copper (Cu) and zinc (Zn) with respect to the ratio Cu/Zn (Chapter 1 and 2);
- regarding the vitamins, the ration should be balanced for vitamins A, D and E (Chapter 1 and 2);
- in addition, comparing the ration composition established using the formulation form (Table 13.6: a ready formatted form available in appendix), to the guidelines of the most common composition of rations displayed Table 13.2, allows for verification at the end of the calculation that the ration is acceptable.

13.2 Calculation of mineral and vitamin supplementation

Rations do not often meet the requirements of the horse in regard to mineral content (tables in Chapter 16 for Ca, P and Mg for all feeds and Chapter 12 Table 12.23 and 12.24 for K, Na and Cl for forages), microminerals (Chapter 16, Appendix 1: forages, and Sauvant *et al*., 2004: extended list of concentrates, see references) and vitamins (Chapter 16, Appendix 3). Hence, rations should be supplemented with minerals and vitamins (mineral vitamin feed supplement – MVFS). The mineral and vitamin feed supplements are offered in conjunction with the base ration, or included in complementary or complete compound feeds offered to balance the ration.

13.2.1 Phosphorus and calcium

The daily recommended allowances are displayed in the tables established for each type of animal (Chapters 3 to 8). By difference between these recommendations and the allowances supplied by the basal optimal ration to achieve the energy and protein allowances (Table 13.1), the shortage of P and Ca are calculated, that is to say the amount of P and Ca that a MVFS should supply and conversely. The ratio Ca/P of this deficit is calculated and a MVFS is chosen with a ratio Ca/P equal or slightly higher.

Table 13.1. Formulation form – example: mare, light horse breed, 1st month of lactation, 500 kg BW.

Feeds	Nutritive value per kg DM					Amount (kg DM)	Daily nutrient and intake allowances				
	UFC	MADC	Ca (g)	P (g)	Mg (g)		UFC	MADC (g)	Ca (g)	P (g)	Mg (g)
Wrapped grassland silage FF 0600 [1]	0.47	53	5.2	3.1	2.4	9.36	4.4	496	48.7	29.0	22.5
Barley CC 0010 [1]	1.14	82	0.8	4	1.3	3.19	3.6	262	2.6	12.8	4.1
Soybean meal CX 0140 [1]	0.94	436	3.9	7	3.3	0.45	0.4	196	1.8	3.2	1.5
(1) Calculated daily total allowances						13 [2]	8.5	954	53.1	45	28.1
(2) Daily recommended allowances (Chapter 3, Table 3.7)						11-15 [2]	8.5	956	56	49	11
(3) Difference (1) – (2)						1	0.0	-2.0	-2.9	-4.0	17.1
% error = (3)/(2)							0	0	-5	-8	155

Composition of the ration as fed

Feeds	Amount (kg)	DM content	Amount (kg)	Cost €/kg	Cost €/day
	(1)	(2)	(3) = (1) : (2)	(4)	(3) × (4)
Wrapped grassland silage FF 0600 [1]	9.36	0.55	17.02	0.24	4.08
Barley CC 0010 [1]	3.19	0.87	3.66	0.22	0.81
Soybean meal CX 0140 [1]	0.45	0.88	0.51	0.34	0.17
					Total 5.06

[1] Code of feeds in tables of Chapter 16.

[2] The calculated daily dry matter (DM) allowances are included in the range of recommendations: Chapter 3, Table 3.7.

Table 13.2. Guide of the composition of the rations.

Type of animal	Physiological status	Production objective	Percentages		Comments[2,3]
			Forages[1]	Concentrate	
Mares	gestation		50-95	5-50	Forage G ↑ to VG //
	lactation		50-95	5-50	Forage M ↑ to VG //
Stallions	rest		85-95	5-15	Straw// + forage M to VG //
	service		60-70	30-40	Straw// + forage M to VG //
w	1 year	optimal growth	40-65	35-60	Forage G to VG ↑ or E //
		moderate growth	65-75	25-35	Forage M to G ↑
Young light horse	2 years	optimal growth	75-80	20-25	Forage G to VG ↑ or E //
		moderate growth	80-85	15-20	Forage M ↑ or G //
	3 years	optimal growth	80-85	15-20	Forage G //
		moderate growth	85-90	10-15	Straw ↑ + hay G //
Young draft horse	1 or 2 years	optimal growth	40-60	40-60	Forage G ↑ to VG //
Growing	1 or 2 years	moderate growth	85-90	10-15	Straw ↑ + hay G //
Fattening	10 months	very rapid growth	30-50	50-70	Forage VG to E ↑
	12 months	very rapid growth	40-70	30-60	Forage VG to E ↑
Working horse					
Light horse	rest to intense work		35-95	5-65	Hay G to VG // + straw //
Draft horse			55-95	5-45	Hay M to G // + straw //

[1] Straw is included in the percentage of forages mentioned.

[2] Straw is separated from the forages in order to mention the specific procdure of distribution.

[3] M = forage of average quality; G = forage of good quality; VG = forage of very good quality; E = forage of excellent quality; ↑ = forages fed free choice; // = forages fed limited.

Commercial mineral and vitamin feed supplements (premixes) are named by their P and Ca content, which is mandatory to have listed on the label. Hence, a supplement can contain between 5 to 12% of P and between 8 to 25% of Ca. A MVFS of category 7-12 provides 70 g of P and 120 g of Ca per kg (or 7 and 12% respectively).

13.2.1.1 In a situation of shortage

The amount of MVFS to be fed daily is calculated by dividing the daily shortage in phosphorus of the basal ration by the percentage of phosphorus in the FMVS (indicated on the label).

$$\text{Amount of MVFS to be fed (g/d animal)} = \frac{\text{deficit of P (g/d animal)} \times 100}{\text{percentage of P in MVFS}}$$

Example 13.10. Calculation of the amount of mineral vitamin feed supplement.

The amount of MVFS of category 7-12 for a daily shortage of 10 g of P will be:

$$\frac{10\text{ g} \times 100}{7} = 143\text{ g/d/animal}$$

If the base ration does not have a shortage or exhibits a very little deficit of P and Ca (less than 10% of recommended allowances), either a MVFS with correct sodium and microminerals content or a block enriched with microminerals should be offered to animals to ensure the balance. In this last case intake should be monitored to confirm that the horses' consumption is adequate. The horses do not often adjust their intake to meet their requirements with this kind of products.

Example 13.11. Recommended amount of P (49 g/day) and Ca (56 g/day) for a mare 500 kg BW during the first month of lactation (Chapter 3, Table 3.7).

The ration previously calculated in the Example 13.6 provides 53 g of Ca and 45 g of P (Table 13.1). The shortage of calcium and phosphorus are 5% (2.9 g) and 8% (4.0 g) respectively. A MVFS should be offered to meet the minerals requirements. The ratio Ca/P of the MVFS should be equal to the deficit thus ¾ (2.9/4.0), hence about 0.8.

13.2.1.2 In a situation of excess

If there is an excess in the ration, namely of calcium (for example, a ration high in dehydrated lucerne), 15% calcium in excess can be accepted if phosphorus (and vitamin D) are totally covered. The horse is tolerant enough to excess of calcium and no important limitation of the absorption of microminerals seems to occur within this limit. The P and Ca allowances should be calculated in respect to those of vitamin D.

13.2.2 Sodium

The MVFS should be checked to see if it provides adequate sodium (Na) on its own to the ration. However, when only a small amount of MVFS is fed, a salt block could be offered free choice to animals rather than finding out a MVFS with adequate sodium content.

13.2.3 Magnesium and microminerals

The total recommended allowances of Mg and the microminerals can be calculated easily by multiplying their optimal concentration indicated in Table 2.1, Chapter 2, by intake of feeds expressed per kg DM for each category of animal (tables of Chapter 3 to 8). The tables of recommended allowances give these calculated requirements (Chapter 3 to 8).

Recommended allowances = concentration (Chapter 2, Table 2.1) × intake kg DM (tables in Chapter 3 to 8) (1)

The Mg and microminerals content of the commercial MVFS, or the MVFS included into compound feeds that have been previously used to balance the ration, should fall in the range displayed in the Table 13.3 to meet the recommended allowances.

The amounts that are actually achieved by MVFS or compound feeds are calculated as followed:

Allowances really calculated = mineral content of MVFS or compound feeds (see label) × Amount of MVFS or compound feed fed (kg DM) (2)

The allowances achieved (Equation 2) and recommended (Equation 1) are compared to evaluate the achieved rate of the requirements. This rate should fall between 80 and 140%.

Example 13.12. Young horse, adult bodyweight 500 kg, growth period, 1st winter (6-12 months), optimal growth.

The horse is fed a ration composed of 5.0 kg DM of grassland haylage, 3.1 kg of a compound feed whose characteristics are displayed in Table 13.4. Table 5.8 of Chapter 5 displays the recommended allowances (to meet). The nutritional balance of the ration (Table 13.4) shows on the third line that the recommended allowances are satisfied for the nutrients displayed in the formulation form, or in excess without risk. It is not necessary to use a MVFS.

Example 13.13. Young horse, adult bodyweight 500 kg, growth period, 1st winter (6-12 months), optimal growth.

The horse is fed a ration composed of 5.0 kg DM of wrapped grassland silage, 2.0 kg DM of barley, 0.15 kg DM of soybean meal and 0.8 kg of dehydrated lucerne (18% CP) thus a total of 8.0 kg DM. Table 5.8 of Chapter 5 reports the recommended allowances (to meet). The formulation form (Table 13.5) exhibits (third line) a shortage of copper and zinc of the ration. MVFS should be implemented. How should it be determined?

Determination of MVFS

The necessity to meet the requirements of animals, while the maintaining nutritional equilibrium, in particular the ratios Ca/P and Cu/Zn, is the challenge to determine 0the MVFS. These ratios are calculated by dividing the corresponding recommended allowances. The amount of MVFS to be offered should be fixed. Then the compatibility of the contents of this FMVS that will be used to fulfil the shortages is evaluated using the Table 13.3. In Example 13.3 (Table 13.5) the calcium and phosphorus of the ration is high enough, but magnesium is in excess (line 6).

The ratio Ca/P of the excesses before correction by the MVFS is 7.5/1.6, thus 4.7. The MVFS will provide little calcium and phosphorus. A moderate supply of MVFS (e.g. 25 g) and a weak Ca/P content should be chosen in order that does not increase again the excess of calcium and phosphorus. Most MVFSs have a ratio Ca/P which varies between 1 and 3. One with a ratio of 1 should be chosen. A MVFS type 8/8, supplying 8 g of calcium and 8 g of phosphorus per 100 g of product and as much calcium without magnesium (otherwise the weakest as possible), is acceptable.

The shortfall of copper is 17.3 mg and that of zinc is 100.1 mg. For 25 g of MVFS to supply 17 mg of copper and 100 mg of zinc, the content of MVFS should be 17/25 × 1000 mg/kg of copper as a result 680 mg and 100/25 × 1000 mg of zinc as result about 4,000 mg. Reading the Table 13.3, column 50 g, it is necessary to divide the range of copper and zinc that are proposed, hence, 400-1000 mg for copper and 1,750-5,000 for zinc (because only 25 g of MVFS is fed), to supply the adequate amount of those microminerals. Hence, the amount of copper and zinc supplied by the MVFS falls within these ranges.

Caution, while the micromineral content of ingredients are stable enough, those of forages are very variable depending on the zones where it is grown. Local agricultural organisations and extension offices which are familiar with regional conditions can advise on the most likely content of the forages.

How much the MVFS supplies appears on the fourth line in the formulation form, the total allowances are displayed on line 5. The balance between recommended allowances and calculated allowances are displayed on line 6, whereas the rates of satisfaction of the requirements are given on line 7. Here in this example the requirements are met. The excess of magnesium is not detrimental. The final report has a Ca/P ratio of 1.6 very close to the requirements and the final Cu/Zn ratio is 0.2 very close to their requirements as well.

13.2.4 Vitamins

The theoretical recommended allowances of each vitamin (expressed in international units, IU or in mg, according to the vitamins) can be calculated using the same procedure as for minerals:

Recommended allowances = concentration (Chapter 2, Table 2.1) × intake kg DM
(Chapter 3 to 8, tables) (1)

The allowances actually achieved by the MVFS or the compound feed including the MVFS that are offered, are calculated as followed:

Allowances actually calculated = vitamin content of MVFS or compound feeds (see label) × amount of MVFS or compound feed fed (kg DM) (2)

The content of vitamins of the MVFS or of the compound feed that includes a MVFS should fall within the range of values displayed in the Table 13.3 to meet the recommended allowances.

Table 13.3. Range of the theoretical composition of the mineral and vitamin feed supplement (MVFS) for magnesium, sodium, microminerals and vitamins for all the types of horses (see chapters for each type of horse for calcium and phosphorus).

Contents	Daily amount		
	50 g	100 g	150 g
Magnesium (%)	6-8	3-4	2-3
Sodium (%)	10-14	5-12	3-10
Copper (mg/kg)[1]	800-2,000	400-1000	250-700
Cobalt (mg/kg)[1]	30-50	15-25	9-16
Zinc (mg/kg)[1]	3,500-10,000	1,750-5,000	1,250-3,300
Manganese (mg/kg)[2]	0-4,000	0-2,000	0-1,300
Vitamin A (UI/kg)[3]	600,000-1,100,000	300,000-550,000	200,000-350,000
Vitamin D (UI/kg)[3]	75,000-150,000	37,000-80,000	25,000-50,000

[1] The requirements for copper, cobalt and zinc are high for all horses except for the fattening horse: the MVFS with content closest to the highest value of the range will be preferentially used.
[2] The requirements for manganese are high only for the fattening horse fed with maize based-diet: MVFS with content close to the highest value of the range will be preferentially used for this kind of animal.
[3] The requirements for vitamins are high for the mares, the stallions and the working horses: MVFS with content close to the highest value of the range will be preferentially used for this kind of animal.

It is only necessary to compare the calculated allowances to the recommended allowances to evaluate the rate at which it satisfies the requirements. This rate should be lower or equal to 150%. Too high of an excess of vitamin A should be remedied to prevent a secondary deficiency of vitamin E and an increase in bone fragility (Chapter 1, 2 and 5). The ratio vitamin A/vitamin D should fall within the range 5 to 10, whereas calcium and phosphorus allowances are sufficient.

Example 13.14. Young horse, adult bodyweight 500 kg, growth period 1st winter (6-12 months), optimal growth.

The horse is fed a ration composed of 5.0 kg DM of grassland haylage, 2.0 kg DM of barley, 0.15 kg DM of soybean meal and 0.8 kg of dehydrated lucerne (18% CP) thus a total of 8.0 kg DM. Table 5.8 of Chapter 5 gives the recommended allowances of 25,900 IU vitamin A/day/animal. To be safe, vitamins allowances from forages are always neglected, because the shelf-life of vitamins is only 5 to 6 months. The vitamin A requirement will be met if 25 g of the previous FMVS will supply 25,900 UI. The vitamin A content of the MVFS should be 25,900/25 × 1 000 = 1,036,000 UI/kg. This value is corresponding to the intermediate value displayed in the column 50 g in the Table 13.3 divided by 2 since 25 g of the MVFS is offered. It is not always easy to find a MVFS corresponding as accurately as in the previous calculation. The main point is that the allowances should meet the requirements and that the excess falls within the range previously mentioned.

Table 13.4. Formulation form – example: young horse, growth period 6 -12 months (adult bodyweight 500 kg). Ration composed of forage supplemented with a compound feed.

Feeds	Nutritive value of feeds per kg dry matter							Amount (kg DM)	Daily nutrients and intake allowances							
	UFC	MADC	Ca (g)	P (g)	Mg (g)	Cu (mg)	Zn (mg)		UFC	MADC (g)	Ca (g)	P (g)	Mg (g)	Cu (mg)	Zn (mg)	Cu/Zn
Grassland haylage FF 0600[1]	0.47	53	5.2	3.1	2.4	5.6	36	5.0	2.35	265	26.0	15.5	12.0	30.0	180.0	
Compound feed	0.9	110	6.0	3.0	1.3	19	80	3.1	2.79	341	18.6	9.3	4.0	58.9	248.0	
(1) Calculated daily total allowances								8.1[2]	5.14	606	44.6	24.8	16.0	88.9	428.9	0.21
(2) Recommended total daily allowances (Table 5.8, Chapter 5)								6.5-8.0[2]	5.10	567	37	25	5	75	375	0.20
(3) Difference (1) – (2)								0.1	0.04	39	7.6	-0.2	11.0	13.9	53.0	
% error = (3)/(2)								1	1	7	21	-1	220	19	14	

Feeds	Amount (kg DM)	DM content	Amount (kg fed)	Cost €/kg	Cost €/day
	(1)	(2)	(3) = (1):(2)	(4)	(3) × (4)
Grassland haylage FF 0600[1]	5	0.55	9.09	0.24	2.18
Compound feed[1]	3.1	0.88	3.52	0.42	1.48
					Total 3.66

[1] Code of feeds in Chapter 16.

[2] Calculated daily dry matter (DM) allowances are included in the range of the recommendations: Chapter 5, Table 5.8.

Table 13.5. Formulation form – example: young horse, growth period, 6-12 months (adult bodyweight 500 kg). Farm made ration.

Feeds	Nutritive value of feeds per kg dry matter							Amount (kg DM)	Daily nutrient and intake allowances							
	UFC	MADC	Ca (g)	P (g)	Mg (g)	Cu (mg)	Zn (mg)		UFC	MADC (g)	Ca (g)	P (g)	Mg (g)	Cu (mg)	Zn (mg)	
Grassland haylage FF 0600[1]	0.47	53	5.2	3.1	2.4	6	36	5.00	2.75	265	26.0	15.5	12.0	30.0	180.0	
Barley CC 0010[1]	1.14	82	0.8	4	1.3	10	35	2.00	2.28	164	1.6	8.0	2.6	20.0	70.0	
Soybean meal CX 0140[1]	0.94	427	3.9	7.1	3.3	19	54	0.15	0.14	64	0.6	1.1	0.5	2.9	8.1	
Dehydrated Lucerne CD 0020[1]	0.57	86	20.0	2.6	1.6	6	21	0.80	0.46	69	16.0	2.1	1.3	4.8	16.8	
																Cu/Zn
(1) Calculated daily total allowances								8.0[2]	5.23	562	44.5	26.6	16.4	57.7	271.9	0.21
(2) Daily recommended allowances (Table 5.8, Chapter 5)								8.0[2]	5.10	567	37	25	5	75	375	0.20
(3) Difference (1) – (2)								0	0.13	-5	7.5	1.6	11.4	-17.3	-100.1	
% error = (3) / (2)									3	-1	20	6	228	-28	-27	
									Daily MVFS supply							Cu/Zn
(4) MVFS supply			80	80	0.0	80	4,000	0.025	0.0	0.0	2.0	2.0	0.0	20.0	100.0	0.21
(5) Allowances Feeds + MVFS = (1) + (4)											46.5	28.6	16.4	77.7	374.9	
(6) Difference (5) – (2)											9.5	4.1	11.4	0	0	
(7) % requirements satisfaction= (5)/(2)											125%	114%	228%	104%	100%	
									Ca/P final		1.6					
									Ca/P requirements		1.5					

Feeds	Amount (kg DM)	DM content	Amount (kg fed)	Cost €/kg	Cost €/day
	(1)	(2)	(3) = (1):(2)	(4)	(3) × (4)
Grassland haylage FF 0600[1]	5	0.55	9.09	0.24	2.18
Barley CC 0010[1]	2	0.87	2.29	0.22	0.51
Soybean meal CX 0140[1]	0.15	0.88	0.17	0.34	0.06
Dehydrated lucerne CD 0020[1]	0.8	0.92	0.87	1.34	1.17

[1] Code of feeds in tables of Chapter 16.

[2] Calculated daily dry matter (DM) allowances are included in the range of the recommendations: Chapter 5, Table 5.8.

13.3 Full formulation form

The form used in the previous examples is a simplified form to describe the principles of the calculation of rations. A form that is more comprehensive has been made. The comprehensive form (Table 13.6) is structured in four parts to identify and then to implement all the major elements of the calculation of the ration:

- Part 1: the composition of the ration (chosen feeds and amount to be offered);
- Part 2: the complete nutritive value of the feeds (and the daily nutrients allowances supplied by the feeds);
- Part 3: the calculation of the ration before mineral and vitamin corrections (comparing the calculated allowances of the ration to the recommended allowances);
- Part 4: The formulation of the MVFS to balance the minerals and vitamins of the ration.

The major nutritional ratios to be calculated and then maintained are displayed in Parts 2, 3 and 4 of the form.

References

References quoted through the text are only listed; for other references which are supporting the chapter, see 'Further reading'.

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Sauvant, D., J.M. Perez and G. Tran (eds.), 2004. Tables of composition and nutritional value of feed materials. Wageningen Academic Publishers, Wageningen, the Netherlands, 304 pp.

Table 13.6. Complete standard formulation form (DM = dry matter).

Part 1. Composition of the ration.

Feeds[1]	Amount (kg DM) (1) = (3) × (2)	DM content (2)	Amount (kg fed) (3) = (1) : (2)	Cost/kg	Cost/day

[1] Table of feeds in Chapter 16.

Part 2. Nutritive value of feeds per kg DM.

Feeds[1]	UFC	MADC	P (g)	Ca (g)	Mg (g)	Cu (mg)	Zn (mg)	Amount of DM (kg DM)	Daily nutrient allowances of feeds										% of forage		
									UFC	MADC (g)	P (g)	Ca (g)	Mg (g)	Cu (mg)	Zn (mg)	Vit.A (IU)	Vit.D (IU)	Vit.E (IU)			
																			MADC/UFC obtained	Ca/P obtained	Cu/Zn obtained
(2) Calculated total daily allowances																					

[1] Table of feeds in Chapter 16.

Part 3. Balance before mineral and vitamin correction.

	Options		UFC	MADC (g)	P (g)	Ca (g)	Mg (g)	Cu (mg)	Zn (mg)	Vit.A (IU)	Vit.D (IU)	Vit.E (IU)	MADC/UFC theoretical	Ca/P theoretical	Cu/Zn theoretical	Vit. A/Vit. D theoretical
	low	high														
(1) Daily recommended allowances[2]																
Consumption (kg DM)																
Energy concentration (UFC/kg DM)																
Protein concentration (g MADC/kg DM)																
			UFC	MADC (g)	P (g)	Ca (g)	Mg (g)	Cu (mg)	Zn (mg)	Vit.A (IU)	Vit.D (IU)	Vit.E (IU)	MADC/UFC difference			
(3) Difference (2) – (1)																
(4) % error = (3)/(1)																

[2] Recommended daily allowances can be found in the tables of Chapter 3-7.

Part 4. Final balance for minerals and vitamins after correction with FMVS

P (g/kg)	Ca (g/kg)	Mg (g/kg)	Cu (mg/kg)	Zn (mg/kg)	Vit.A (IU/kg)	Vit.D (IU/kg)	Vit.E (IU/kg)	Amount (kg)		P (g)	Ca (g)	Mg (g)	Cu (mg)	Zn (mg)	Vit.A (IU)	Vit.D (IU)	Vit.E (IU)	Ca/P final with MVFS	Cu/Zn final with MVFS	Vit. A/Vit. D final with MVFS
									(4) MVFS supply											
									(4) Total daily allowances calculated											
									Final balance											
									% of (1)											

Chapter 14. Environmental impact of horses

Geraldine Fleurance, William Martin-Rosset, Bertrand Dumont, Patrick Duncan, Anne Farrugia and Thierry Lecomte

Ever since the Rio summit in 1992, protection of the environment has become a preoccupation of the world of politics and involved scientists. It has been confirmed by the next summits in Kyoto in 1997 and Copenhagen in 2009 despite the difficulties encountered in obtaining a consensus concerning the measures to take. A new conference is planned in Paris in 2015 to design a long term strategy regarding the emergency of the situation. Agriculture is directly concerned because of the emissions that production animals release and equally the impacts of animals on vegetation and the rural landscape. This chapter has the objective of making the point on these two aspects: controlling biodiversity and managing emissions in order to locate horses regarding other farm animals, within the context of the problem and propose possible solutions.

14.1 Impact of the pasturing horse on plant and animal biodiversity of pastured environments

Recent progress in animal identification has provided evidence of a large increase in the number of equids (horses, donkeys, and their hybrids) in France. A census, in late 2008 counted 900,000 equids, an increase of about 20,000 per year from 2006 (ECUS, 2010). Even if this number is small compared to cattle numbers (19,199,000 heads counted in 2010, Institut de l'Elevage), horses and their relatives are playing an increasingly important role in pasture area maintenance. Also, they are being used more and more in preserving biological diversity in regions with high ecological value (e.g. nature reserves), where they pasture alone or in combination with ruminants. In this context, new questions concerning their impact on the dynamics of the areas they graze emerge and are registered, notably in discussions pertaining to development of farming systems important to the environment (cf. high nature value farming; European Forum for Nature Conservation and Pastoralism; www.cfncp.org). Research on these themes concerning equids has largely been conducted with horses in Europe (Belgium, France, Iceland, Italy, Poland, Portugal, Spain, Switzerland and the Netherlands) and in North and South America (USA, Argentina), but is still few (Fleurance *et al.*, 2012; Osoro *et al.*, 2012). Results, such as they are, suggest that the impact on pastures of equids follows the same principles as those found for other large herbivores. Nonetheless, their particular digestive physiology gives them a large intake capacity and their double row of incisors allows them to graze more closely than ruminants of the same size. These characteristics can lead to a significant increase in the structural variation of pasture plants. The objective of this section is to summarise the available research results concerning the impact of equine grazing on biological diversity of the pasture environment.

14.1.1 Impact of equine grazing on vegetation communities

14.1.1.1 Mechanism of action of large herbivores on floral diversity in pastured environments

Grazing is an effective economic direct use, but often heterogeneous, of the primary production of grasslands and their surroundings. Selection and consumption of the vegetation by the animals, the

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spreading of their excreta and their trampling modifies the vegetation's spatial structure. This result in a wide range of habitats, which facilitates the coexistence of species adapted to different ecological niches and promotes plant diversity. All the mechanisms involved are often explained and divided into two main types: those that are a result of a direct effect on plants by ablation or tissue injury and those that are the result of an indirect effect and most often differed.

Direct effects on plants by large herbivores are closely related to selective removal and trampling. The removal of plant material by the animals generally results in a decrease in biomass both at the root system level and the aerial portion. Consumption of the reproductive organs by large herbivores can also affect flowering and seed production. Removal of other parts of the plant can lead to reduced flowering and the number and size of seeds due to the reduction of available resources. Trampling by the animals also significantly affects vegetative tissues often leading to death of the plant or of the part located above the damage site. Finally the deposition of faeces and urine can cause the plant physical damage or have local toxic effects even if its principal impact is indirect through nutrient cycling and seed dispersal.

Among the indirect effects of large herbivores on plants, the effects on vegetation produced by the application of nutrients provided by the excreta rank highest. These products affect biogeochemical cycles, which support primary production, principally by accelerating the nitrogen cycle. At the plot level, equine specific behaviour in regard to excretion (separation of areas of feeding from elimination) result in fertility transfer, with the depletion of pastured areas and enrichment of roughs. (Chapter 10, Section 10.1). Large herbivores also enhance the distribution of seeds throughout the countryside by carrying them in their coats or depositing them in their faeces. Finally they can enhance initial seedling growth by creating gaps in the plant cover. These are favourable sites of germination as the seedlings are protected from competition with mature plants. These gaps may be created by trampling (or digging for mineral salts for example) or appear after plant death due to herbivore droppings.

Within grazing systems, specific plant variety depends upon the colonisation process by the available species quantities on a large spatial scale and species extinction on a local scale, resulting primarily from competition mechanisms. Competition between plants may be defined as the result of an interaction among several individuals competing for a resource of limited availability, leading to an alteration of growth, reproduction and/or individual survival (Chapter 10, Sections 10.1; 10.2 and 10.3). Through their impact on the colonisation process and species disappearance, large herbivores have important determining effects on plant diversity in the environment (Chapter 10, Section 10.1.4). While herbivores reduce or alter competitive interactions among plants, their presence leads to better coexistence among species and increased diversity. However, in situations where grazing tends to increase the dominance of an already dominant species, or under intensive, prolonged grazing where species resistant to grazing survive, plant diversity declines. This supports Grime's 1973) hypothesis of 'intermediate stress' stating that maximal richness of plant species occurs at intermediate levels of biomass (e.g. corresponding to moderate grazing pressure).

Herbivore effect on diversity of pastured environments is also highly dependent on the selectivity of different types of animals. Size, digestive physiology, mouth and dental morphology of the herbivorous species dictate the different food choices and, therefore, potential impact on sward plant diversity. Results presented in this work illustrate different impacts of horses and ruminants.

Age and sex effects of the animal are generally related to its size. Similarly for breed effects, where there is sometimes a difficulty of disassociating them from previous feeding experiences, which it is recognised, have an influence on choices as adults. In grazing situations involving several species of herbivores, effects on vegetation can be different from those characterised when grazed by a single species. Different species of herbivores have compensatory effects when their eating habits differ and lead to enhanced utilisation of the plant cover.

14.1.1.2 Effect of exclusive equine or equine-bovine grazing

The majority of studies aimed at analysing the effects of equine grazing on plants arise from humid regions. Research studies, conducted primarily in the nineties, were designed with the conservation of highly sensitive environments in mind. These studies mostly used the technique of exclusion where grazing was restricted from certain areas and their evolution was compared to grazed areas. In the Camargue (South east zone of France: Mediterranean coast), suppression of equine grazing has, therefore, after several years, resulted in the development of certain perennials species (reed grass (*Phragmites*) in marshes, cocksfoot (*Dactylis glomerata*) and quackgrass (*Agropyron*) in the meadows) and the almost complete loss of annual species (Figure 14.1). The opening up of the environment through grazing and trampling by animals encourages the replacement of light competitive species by shorter species and/or those competitive for soil nutrients, which permits the coexistence of a larger number of species. In the Netherlands, in a dune environment, horses have limited the development of competitive grasses (e.g. sand sedge (*Carex arenaria*), common calamagrostis (*Calamagrostis epigetos*) and improved species variety to a level comparable to non-pastured areas (Lamoot *et al.*, 2005). In a mixed, equine-bovine pasturing situation in a wetlands area in the Netherlands, the eating and trampling by the animals allowed control of growth of the common reed, *Phragmites australis,* and cirses, *Cirsium* spp., and encouraged the development of short species (e.g. common bluegrass, *Poa trivialis*), thus improving the forage value of plant population. Herbivore activity

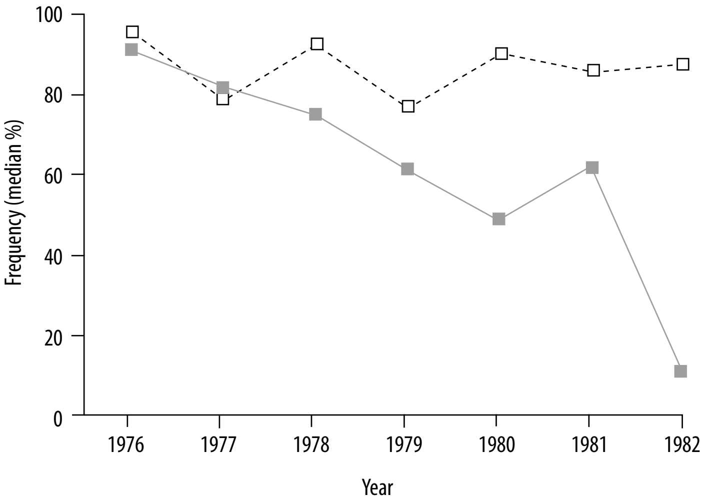

Figure 14.1. Response of the annual daisy (*Bellis annua*) to the elimination of equine grazing in exclusion areas (solid line) compared to pastured areas (dotted line) (from Duncan, 1992).

has been particularly important during periods when the quantity of their preferred resources decreased in the surrounding grasslands. In the Camargue and in the Poitevin marsh (Mid-West zone of France: close to Atlantic coast), prohibited equine -bovine mixed grazing has rapidly lead to decreased specific plant abundance and an increase in the quantity of certain species smooth cord-grass (e.g. *Aeluropus littoralis* in the Camargue (Mesleard *et al.*, 1999), creeping wheatgrass (*Elymus repens*) in the Poitevin marsh (Loucourgaray *et al.*, 2004). In the grassland plains of Montana and Wyoming, pasturing of horses with wild species (sheep and deer) has proved necessary to maintain uncompetitive species, such as hair-like feather grass (*Stipa comate*) and Sandberg bluegrass (*Poa secunda*) (Fahnestock and Derling, 1999). Finally, in the extensive agricultural areas of the Central mountains in France (Massif central), repeated pasturing by horses in moist mountainous regions and trampling of the ligneous species during defecation has resulted in the progressive regression of woody species: common bilberry (*Vaccinium myrtillus*), marsh blueberry (*Vaccinium uliginosum*), hairy greenweed (*Genista pilosa*), and common heather (*Calluna vulgaris*) and the moorland grasses: sheep fescue (*Festuca ovine*), wavy hair grass (*Deschampsia flexuosa*), moor matgrass (*Nardus stricta*) to the benefit of forage grasses (red fescue (*Festuca rubra*) and common bentgrass (*Agrostis tenuis*) (Loiseau and Martin-Rosset, 1988).

The magnitude of the impact of grazing by horses on the plant community is, however, dependent on abiotic factors, such as soil fertility and the amount of precipitation. In the Nevada desert, therefore, the variety of species in restricted areas is three times greater than in the areas grazed by horses (Beever and Brussard, 1990). This difference in comparison with earlier cited studies is explained by totally different environmental conditions. In particular, the positive effect of grazing by horses on the colonisation capacity of other plant species can be limited by the reduced productivity of the site and the weak recoverability of the vegetation. The benefits of competition for light do not exist in such an environment. Besides, the dominant species in desert environments, adapted for water retention through mechanisms that limit transpiration (e.g. spines) and including secondary components, are generally disliked by herbivores. Horses can then have preferentially selected rarer species, resulting in a population decrease or extinction. Apart from abiotic factors common to this type of environment, it is also possible that the negative impact of equine grazing on biodiversity results from the fact that horses, indigenous to Eurasia, appear here as an introduced species.

14.1.1.3 Effect of stocking rate on equine grazing

Very few studies have analysed the consequences of different styles of horse grazing management on vegetation diversity. The influence of stocking rate under continuous grazing was the only objective of several studies. Scientists in Iceland have, over 8 years, analysed the influence of summer grazing by horses at 3 stocking rates (190 kg BW/ha, 330 kg BW/ha, 406 kg BW/ha) (Magnusson and Magnusson, 1990). At the highest stocking rate, the decrease in plant height and uniformity (average height <5 cm) as well as the increase in the proportion of bare soil resulted in the growth of new species, primarily bryophytes. These species, adapted to northern regions' specific climatic conditions, contribute to species abundance in the environment, but are, however, of little interest from an animal production viewpoint. The abundance of species preferentially grazed by horses (black sedge (*Carex nigra*) and common bentgrass (*Agrostis capillarus*)) decreased to the benefit of species more tolerant to grazing, and more adapted to disturbed and mineral dependent habitats.

In the fertile fields of Limousin (430 m.a.s.l; West central France), INRA and IFCE have quantified the impact of groups of 5 or 3 saddle horses continuously pasturing areas of 2.7 ha from mid-May to the end of July and from early September to mid-November (Fleurance *et al.*, 2010). These two stocking rates (1000 vs 600 kg bodyweight/ha) have resulted in a divergent evolution of legumes which have increased from 4 to 16% of the grazed area surface after 4 years of the high stocking rate while remaining constant at 8% under the lighter stocking rate. Species abundance (on average, 28 plant species per area) on the other hand was not affected by stocking rate after 4 years. An analogous conclusion was drawn in the natural moist grasslands of the Poitevin Marsh (Mid-West France: close to Atlantic coast), where, after 5 years under treatment, the number of plant species (on average 44 species per area) was not affected by the stocking rate of horses ranging from 300 to 900 kg bodyweight/ha (Amiaud, 1998). These two results may be explained by the existence of a heterogeneous structure of plant cover (i.e. a mosaic of short and tall patches) in the areas pastured by horses over the range of stocking rates studied.

Among domestic herbivores, horses are, in effect, characterised by their differential use of grazing areas. Thanks to their double rows of incisors they create and maintain closely grazed areas interspersed among areas of sparsely grazed tall forage where they concentrate their droppings (Chapter 10, Section 2.2.1). Some authors have observed a certain inter-annual stability in the mosaic of short grazed areas and roughs conducive to a functional divergence in the vegetation. In the natural grasslands of the Poitevin Marsh, studies have shown that the increased structural diversity of the vegetation found under equine grazing allows a coexistence of plant species comparatively more important than a more uniform bovine pasture or to an ungrazed control area.

14.1.1.4 Complementarity with cattle may increase the value of mixed pasturing

The feeding pattern of horses on pasture provides a close similarity with that of cattle. Nonetheless, horses make less extensive use of dicotyledons than ruminants as they are less capable of detoxifying the secondary metabolites of these plants. Thus they are preferentially grass specialists (Chapter 10, Section 2.2.1). In permanent grasslands, some authors have provided evidence of a significant effect of herbivorous species (cattle, sheep, horses) on species abundance and the wealth of dicotyledons (Stewart and Pullin, 2008). The latter is greater in fields pastured by horses even if the absolute amounts are limited. On the other hand, horses seem less capable than cattle in limiting the expansion of woody plants under lower stocking rates. In the Netherlands, a natural moist grassland pastured by horses was rapidly invaded by black elderberry (*Sambucus nigra*) while this process was dramatically reduced in a cattle pasture at the same stocking rate (Vulink *et al.*, 2000)In Belgium, some authors have observed significant use of creeping willow (*Salix repens*) by cattle while horse were unable to prevent grassland invasion by this species. INRA conducted work in humid low mountain areas (Massif Central) which showed that trampling by horses could have a significant effect on certain low growing woody stands of blueberries (*Vaccinium myrtillus*) (Loiseau and Martin-Rosset, 1988).

Due to their digestive physiology, horses are less constrained than ruminants by the necessity to reduce the size of food particles. In this case their intake is not as limited by vegetation quality. Compared to cattle, horses are characterised by an elevated intake, especially of coarse forages (Chapter 10, Section 2.1.2) and appear more efficient in controlling vegetation at similar stocking rates. In the Vernier Marsh (Mid-West France: close to Atlantic coast), horses have effectively contributed to limiting the quantity of common rush (*Juncus effuses*) compared to cattle that consume little of it (Lecomte and Le Neveu, 1992). In the temperate moderate mountain area (Massif Central: Central mountains in France), the horse's considerate intake capacity has similarly permitted a considerable regression in grasses of low forage value, e.g. moor matgrass (*Narda stricta*), wavy hairgrass (*Deschampsia flexuosa*) and improved development of high value forage grasses: red fescue (*Festuca rubra)*, bentgrass (*Agrostis tenuis*) in comparison with cattle grazing (Figure 14.2). Horses have thus improved the pastoral forage value of the vegetation and increased species abundance compared to grazing with cattle. In mixed grazing, introducing cattle with horses following grazing by horses has reduced these positive effects, while the introduction of horses with cattle after horses have grazed has produced beneficial effects (Loiseau and Martin-Rosset, 1988). Grazing with horses as opposed to sheep is again of interest for limiting the spread of nard and improving the pasture value of the forage cover (Martin-Rosset *et al.*, 1981).

The practice of mixed grazing is based on the complementary capacity for selection by animal species to best utilise diversified resources. In the Poitevin Marsh mixed horse-cattle grazing is seen to be most favourable in terms of botanical diversity and in improving the composition of the tall grass areas less used by horses. In effect, the cattle, not being able to graze the closely cropped areas, are forced to the tall grass areas and have limited the development of competitive nitrophile species in those areas (Loucourgaray *et al.*, 2004). In average mountain areas, studies conducted by INRA have also concluded that a major benefit of mixed horse-cattle grazing is in controlling the early growth of woody plants: birch (*Betula* spp.), trembling aspen (*Pepulus tremula*), white willow (*Salix alba*), common hazelnut (*Corylus ayellana*) compared to cattle alone (Carrere *et al.*, 1999). Extensive grazing by these species has, nevertheless, failed to control development of Scotch broome (*Cytisus scoparius*) that has been well established. The relative proportion of effects related to consumption of adult plants, young seedlings and to trampling deserves to be analysed in order to interpret apparently contradictory results discussed above.

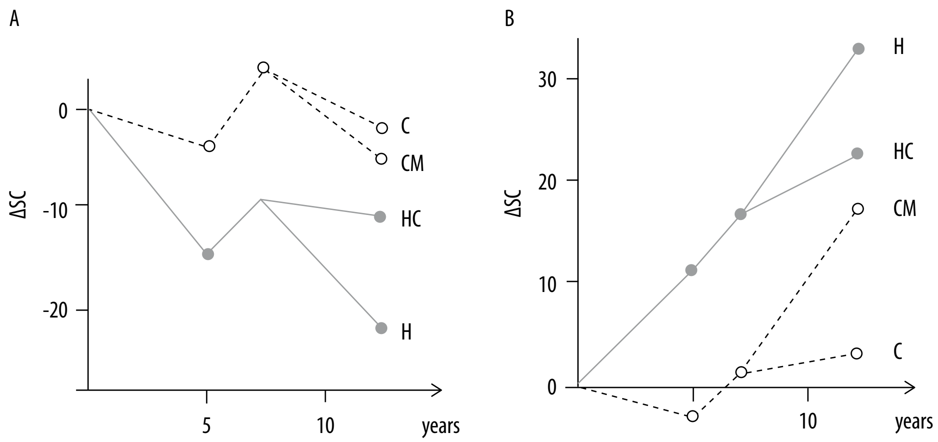

Figure 14.2. Variation in the species contribution (SC) of grasses of low or high forage value over 12 years of single or mixed species grazing (H: horses, C: cattle, HC: horses then mixed, CM: cattle then mixed) (Loiseau and Martin-Rosset, 1988).

14.1.2 Impact of equine grazing on animal communities

14.1.2.1 Mode of action of large herbivores on animal diversity in grasslands

Large herbivores play an important role in the maintenance of animal diversity in pastured environments. As with plant diversity, a moderate grazing intensity generating heterogeneity is generally considered favourable to abundant animal species diversity as it allows the coexistence of several habitats. However, if grazing has, as a specific objective, the conserving of a group of species, grazing intensity must, as a priority, be rationalised as a function of the animals' biological cycle (Van Wieren, 1998).

Birds have been studied most extensively with respect to their response to grazing by large herbivores. In several species the different heights generated through grazing plays an important role in several vital functions. A number of species make use of areas of tall grass for nesting and are, therefore, especially sensitive to increases in grazing pressure. On the other hand, consumption of dominant vegetation by large herbivores favours those species of small, herbivorous birds, which need short, high quality grass for their own nourishment. In reed beds large herbivores can increase the available water surface area, which favours species that use this habitat for resting, food (e.g. ducks and coots), or nesting (e.g. grebes). The majority of small mammals encountered in grasslands prefer tall plants cover for protection from predators. For invertebrates, the principal negative effects of grazing by large herbivores is in the decrease in number of flowering plants in certain communities as well as a decrease in the quantity of litter, the height of plant cover, and a more extreme microclimate, depending on the group. The insect population rapidly readjusts to differences in vegetation structure generated by stocking level (Dumont et al., 1999). Work conducted by INRA has shown that the number of individuals and species of *Orthoptera* (grasshoppers and crickets) and *Lepidoptera* (butterflies) increases quickly with light stocking rates when compared to higher stocking rates. For the latter, changes closely parallel those of flowering plants. Nevertheless, a high stocking rate can be positive for other species, for example the coprophagic dung beetles or certain coleopteran hunter-runners that need areas of short grass. Certain *Orthoptera* need short grass areas or a high, dense cover at different times of their cycle. Overall, a reduction in stocking rates permits the coexistence of a larger number of species due to habitat diversity, which validates existing theoretical models and corroborates a number of experimental studies.

14.1.2.2 Equine grazing and grassland animal diversity

Birds

Several studies, primarily carried out in humid regions, illustrate how grazing either by horses alone or in combination with cattle can be favourable to birds. In the Camargue, horse-cattle grazing has increased the quantity of food resources for herbivorous and seed eating water birds, e.g. Gadwall duck (*Anas strepera*) and Mallard duck (*Anas platyrhynchos*) (Duncan and D'Herbes, 1982). Through limiting the development of aerial parts of plants, e.g. maritime bulrush (*Scirpus maritimus*) and common reeds (*Phragmites australis*), domestic herbivores increase the amount of light available to submerged seagrass and algae consumed by birds. Similarly, in the Netherlands, control of common reeds (*Phragmites australis*) by horses and cattle has allowed increased accessibility of several species birds of prey that need an open habitat (e.g. common spoonbill (*Platalea leucorodia*)) (Vulink, 2001). In the natural humid grasslands of the marshes of Mid-west France studies showed that forage height was a crucial characteristic in feeding of herbivorous *Anatidae* (geese, ducks) and that the attractiveness of the site varies with the type of domestic herbivore (horse or cattle). As well, closely grazed areas (<4 cm) created by horses proved favourable to Eurasian wigeon (*Anas penelope)* as they benefit from early, high quality forage growth (Durant *et al*., 2002). On the other hand, a taller (~10 cm) more uniform plant cover generated by cattle favours the larger grey goose (*Anser anser*), which needs more abundant grass. Short vegetation produced by grazing horses is also of benefit to insectivorous birds, which can more easily detect prey in the closely grazed areas, e.g. wheatear (*Oenanthe oenanthe*) and wagtail (*Motacilla alba*) (Arlt *et al*., 2008; Hoste-Danylowe *et al*., 2010). A cascade of effects can sometimes be observed: on an island in North Carolina (USA), imported horses have caused a decreased recovery of dominant plant species (cord grass (*Spartina alterniflora*)) and, thus, nesting sites for the laughing gull (*Larus atricilla*) and Forster's stern (*Sterna forsteri*). The decline of these birds, characterised by an aggressive behaviour, has allowed the development of species abundance two times greater in the sites where horses were present compared to ungrazed sites (20 vs 10 species) (Levin *et al*., 2002). Among the birds identified in grazed sites, 17 species preferentially consume benthic invertebrates, whose accessibility was improved through the opening of the banks by the horses.

A single study, conducted in Argentina, documented the effect of different grazing pressures on birds (Zalba and Cozzani, 2004). Certain bird species (e.g. Southern lapwing (*Vanellus chilensis*)) were observed exclusively in sites where the stocking rate was high (30 horses/km^2) while others (e.g. Pipit (*Anthus* spp.)) preferred lightly grazed areas (6 to 17 horses/km^2). Generally, species abundance and the quantity of birds have been greatest on sites where the density of horses was intermediate or void compared with heavily grazed areas. The latter were characterised by a lack of diverse habitats and a 5 times greater predation pressure on eggs.

Small mammals

Few studies have analysed the impact of grazing by horses on populations of small mammals. In the Camargue, the cocksfoot areas removed from grazing by horses have been colonised by local voles (*Pitymys duodecimcostatus*); probably because of increased plant cover height and absence of soil compaction (Duncan, 1992). In the New Forest, species diversity and small mammal population size (mice, voles, and shrews) has also been greater in areas removed from mixed grazing by ponies, cattle and deer (Hill, 1985). A facilitating effect of grazing by large herbivores for small herbivorous mammals has, however, been documented in a study where rabbits benefitted from closely grazed areas maintained by large herbivores, including horses, as the rabbits were unable to maintain the closely grazed areas on their own (Oostervelt, 1983).

Invertebrates

The influence of horse grazing on the population of *Orthoptera* has been analysed in a dry meadow of the Causse Mejean (south central dry plateaus France) (Tatin *et al*., 2000). With the exception of the roughs, the amount of tall grass reduced considerably when horses were present (grazing pressure was between 1.9 and 5.4 horses/ha depending upon the appearance of the vegetation) in comparison with ungrazed areas. Nineteen species of *Orthoptera* have been counted in the pastured areas against 16 species in the ungrazed areas with 14 species common to both. The five species present exclusively in the grazed sward were characteristic of open habitats. The species abundance of the group of

Orthoptera was not however, significantly influenced by the applied treatment. In fertile grasslands under two stocking rates of horses (1000 kg bodyweight/ha vs 600 kg bodyweight/ha) INRA and IFCE have shown after 4 years of treatment application a positive effect of lower stocking rate on species abundance of species of beetles and grasshoppers with an affinity for tall grass (>10 cm) (Fleurance *et al.,* 2010). Species abundance of beetles and grasshoppers was not however, affected by stocking rate. In the semi-natural grasslands of Sweden targeted selectivity of sheep for flowering plants has limited the availability of nectar and in consequence species abundance of butterflies. In contrast the areas grazed by horses had a superior number of butterfly species, identical to those counted in the areas grazed by cattle or in the ungrazed areas (Figure 14.3). In the Vernier marsh species abundance of *Syrphidae* (flower eating insects) has increased in areas under extensive grazing by horses and cattle in comparison with the areas used intensively or ungrazed.

In grasslands, earthworms play a determining role in the preservation of biodiversity by contributing to the feeding of a number of European vertebrates and in stimulating the vertical migration of the soil seed bank. Research conducted in the Rhone river valley (France) showed that a relatively low earthworm biomass in locations not pastured for several years could be increased by 10 times after 3 years of extensive pasturing with horses. Finally, a Swiss study on the impact of pasturing by herbivores (horses, cattle, and sheep) on land snails in permanent grasslands in highlands showed that species abundance as well as the abundance of snails was independent of herbivore type. These did decrease, however, as grazing pressure increased (Bochi and Baur, 2007).

14.1.3 Conclusion

Increases in horse numbers in France and Europe and the use of pasture grass as a food resource gives them a significant role in pasture ecosystem management. Horses are also used as a conservation tool in protected natural spaces. However, references concerning the impact of horse grazing on

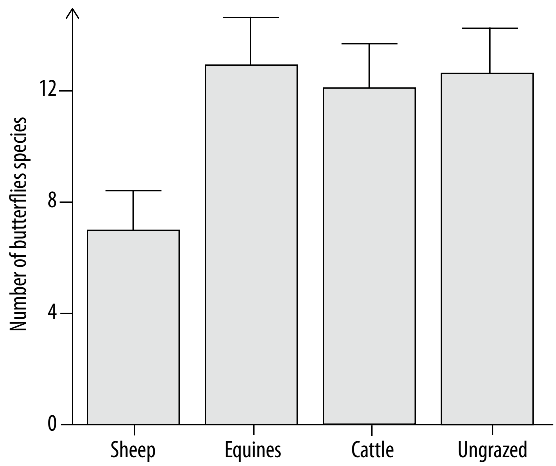

Figure 14.3. Effect of grazing on butterfly species abundance in semi-natural grasslands (Ockinger *et al.*, 2006).

the biological diversity of grasslands are still limited. Because of this fact in this chapter we have exhaustively identified all the French and international work on this theme. The majority of available results have been acquired in specific environments, primarily wetlands. Horses have a number of assets, complementary to those of domestic ruminants, for preserving or enhancing grassland biodiversity. In particular, horses are characterised by the capacity to consume coarse forages, which gives them the means to control competitive grasses and maintain open environments. Their variable mode of grazing (i.e. they maintain closely grazed areas among a matrix of tall grass) promotes, at least for a time, the coexistence of a large number of plant and animal species in the ground cover. They consume broadleaf plants less extensively than ruminants but complementary studies will be required to determine in this behaviour is conducive to enhancing the diversity of flowering plants and pollinating insects. Finally trampling by horses may also limit the development of woody plants. The implicated mechanisms appear to be known, but quantified results are missing for most environments and for the groups of organisms central to conservation programs. Available studies are also often too short to evaluate the long term impact of equine grazing. In the future, horse management techniques to enhance the permanent grassland diversity, must be developed along with their animal production consequences; this over the range of environments representative of the areas of production and more marginal areas.

14.2 Waste

During the periods of production and use horses produce waste that is directly a result of the more or less complete digestion of the feeds consumed to meet their nutritional requirements. This waste includes methane, nitrogen and minerals. They have been determined essentially from studies of digestion and metabolism conducted on horses and/or ponies.

14.2.1 Quantitative evaluation of enteric methane emissions

Emissions of methane by animals, including all production species, represent 97% of methane produced by agriculture in France. Emissions arise on one hand from enteric methane produced in the digestive process and on the other from animal waste. Enteric methane represents, in France, 45% of total emissions due to the large number of herbivores: primarily ruminants but also equines to a lesser degree accounting for respective numbers of 32 million cattle, sheep and goats and 1 million horses. The potential for global warming due to methane is from 21 to 23 times greater than for carbon dioxide (CO_2) but its half-life in the atmosphere is short (12 to 20 years). Methane reduction can, therefore, have an influence on the greenhouse effect in several decades.

Methane emission in horses has been evaluated in three stages: an estimation of the effect of horses, the development of a predictive model for methane emission from the quantity of methane emitted by a category of horses.

The estimation of the number of horses is taken from statistics published in the ECUS annuals edited in 2007 by IFCE (with projections for 5 years) and identified by breeds: draft, light (racing, sport, leisure), ponies, donkeys and in various categories: mares, stallions, foals, other horses in order to account for requirements and specific nutritional provisions (therefore the type of diet) for each category (Table 14.1).

Table 14.1. Emission values and methane emissions for equids in France (from Vermorel *et al.*, 2008).

	Annual numbers (× 1000)	Amount of emissions (kg/head/yr)	CH_4 total (t/yr)	Equids (%)
Draft breed mares, lactating	51	29.4	1,489	7.4
Draft breed mares, not pregnant	38	19.4	734	3.6
Draft breed foals slaughtered at 8 months	27	3.7	101	0.5
Draft breed foals slaughtered at 12 months	7	13.5	92	0.5
Draft breed foals and fillies for replacements (0-36 months)	27	21.6	594	2.9
Draft breed stallions	3	22.3	60	0.3
Saddle mares (racing, sport and leisure) lactating	90	25.1	2,273	11.2
Saddle mares (racing, sport and leisure) not pregnant	23	17.5	402	2.0
Other horses, sport and leisure	381	20.4	7,784	38.5
Foals, racing sport and leisure (0-36 months)	110	19.9	2,187	10.8
Stallions, racing, sport and leisure	9	23.5	211	1.0
Racing horses	16	30.2	488	2.4
Race breed foals (0-24 months)	60	17.9	1,071	5.3
Race breed fillies and colts (24-48 months)	60	30.2	1,812	9.0
Total horses	900	21.4	19,298	95.5
Ponies and donkeys, lactating	13	14.6	188	0.9
Non-pregnant females, ponies and donkeys	25	10.0	252	1.2
Stallions, ponies and donkeys	2	11.5	22	0.1
Ponies and donkeys (0-3 years)	35	12.7	442	2.2
Total ponies and donkeys	75	12.1	904	4.5
Total equines	975	20.7	20,202	100

The enteric emissions of methane have been estimated from the energy requirements of horses expressed as UFC developed in 1990 by INRA for different categories of equids (INRA, 1990). Requirements were converted into digestible energy (DE) by using the prediction equations of the UFC system (Chapter 1 and 12). Methane emissions were then estimated (ECH_4 %DE) from the ingested amount of digestible energy and verified from measurements made on horses by INRA (Vermorel *et al.* 1997).

$$ECH_4 \text{ (\% DE)} = 7.57 - (0.12 \times 28.4 \text{ CF \%}) - (0.01 \times \text{CP \%}) - (0.05 \times \text{SC \%})$$

Where:

CF = crude fibre;
CP = crude protein;
SC = soluble carbohydrate.

Methane emissions have thus been calculated for each equine category listed in Table 14.1 taking into account their state and physiological stage (maintenance only, gestation, lactation, growth, work) and type of feed corresponding to housed or on pasture. In practice the calculation of daily methane emissions using the recommended allowances in UFC (INRA, 1990) and the average composition of diets fed in France were carried out according to a step-wise procedure described by Martin-Rosset *et al.* (2012).

The annual release of enteric methane by equids has been calculated as 20,202 tonnes from a total of 975,000 animals. This gives an emission number of 20.7 kg/animal/yr. For the lactating mare the number is higher: 29.7 kg, which represents 34% of the value calculated for the milking cow (Vermorel *et al.*, 2008). Overall, the total enteric methane emissions from equids in relation to all farm animals accounts for 1.5% compared to 90% for ruminants.

14.2.2 Quantitative evaluation of nitrogen and mineral waste

14.2.2.1 Faecal loss

The adult horse weighing 500 kg at maintenance fed free choice at through with only fresh forage eliminates daily, on average 3.95±0.47 kg of faecal DM (coefficient of variation = 11.8%) using the compilation of digestion trials carried out at INRA to set up the tables of the chemical composition and the nutritive value. Stated alternatively, this is 8 g DM/kg BW for an average intake of 9.40±0.68 kg DM (coefficient of variation = 7.2%) or 19 g DM/kg BW.

The quantity of faeces increases from 15 to 35% with increases in dry matter content of fresh forage harvested during the same growth cycle. Individual variability in the quantity of faeces produced by animals is, on average, 9.0% over the pasture season. This increases during the 1st forage growth cycle and stabilises over succeeding cycles.

The faeces quantity decreases by 12% on average if horses are supplemented with 30% concentrate feed on a total dry matter ingested basis, since they will decrease intake of forage, as concentrate is substituted for forage. In stable feeding, the average rate of substitution on a diet of natural meadow hay is 1.2 kg less forage for each 1.0 kg of added concentrate intake (Chapter 1, Section 1.2.3.3).

Excretion of faecal nitrogen

The amount of nitrogen in the faeces of a 500 kg horse at maintenance consuming, free choice, fresh, natural meadow forage over 3 cuttings per year is, on average, 132±24 g of faecal CP/kg DM or 1.02±0.11 g CP/kg BW (Table 14.2) with a coefficient of variation of the interaction of cutting and stage of 10.8%. On average there is little difference between cuttings but it decreases within cuttings in general for the 2 first cuttings of spring and summer by 26 and 15% respectively (Figure 14.4). Individual variation in the CP content of faeces attributable to animals is from 10.5 to 13. 6% between cuttings and 11.9 to 12.7% within cuttings.

The daily excretion of nitrogen by a 500 kg horse is, on average, 514±52 g CP/d/al. for an entire pasture season (April-October: 210 days), e.g. a total of 108 kg of crude protein (or 17 kg of nitrogen: 108/6.25). The daily nitrogen excretion can be estimated with the help of an equation developed in adult horses consuming only fresh natural meadow forage This equation is completely consistent (same parameters) with that established by INRA in horses consuming dry forage fed in a trough (Table 14.3). However, the equation established for dry forages has an advantage due to the larger

Table 14.2. Faeces eliminated by a light horse stable-fed, free choice a natural meadow harvested green (n=5 animals) (adapted from Chenost and Martin-Rosset, 1985; Martin-Rosset, unpublished data).

	Intake, chemical composition %			Intake (kg BW)	Excreted (kg BW)			Season
	DM	CP/DM	Ash/DM	g DM	g MS	g CP/DM	g ash/DM	
1st Cutting								
Stage 1	15.0	17.9	10.4	19.0	7.0	1.21	0.11	
Stage 2	16.6	15.1	10.1	19.3	7.5	1.01	0.11	Spring
Stage 3	18.4	13.6	9.2	18.6	7.8	0.90	0.12	
2nd Cutting								
Stage 1	19.8	12.7	11.0	20.3	8.9	1.11	0.16	Summer
Stage 2	26.6	11.7	12.8	17.5	8.6	0.94	0.18	
3rd Cutting								
Stage 1	23.3	20.5	13.8	16.3	7.4	0.97	0.10	Fall
Stage 2	26.3	15.4	20.8[a]	19.6	8.6	0.98	0.19[a]	
Average			18.7	7.8	1.02	0.14		
St. Error			±1.3	±0.9	0.11	0.04		
Coefficient of variation (%)			7.0	11.5	10.8	28.6		

[a] Contaminated with soil.

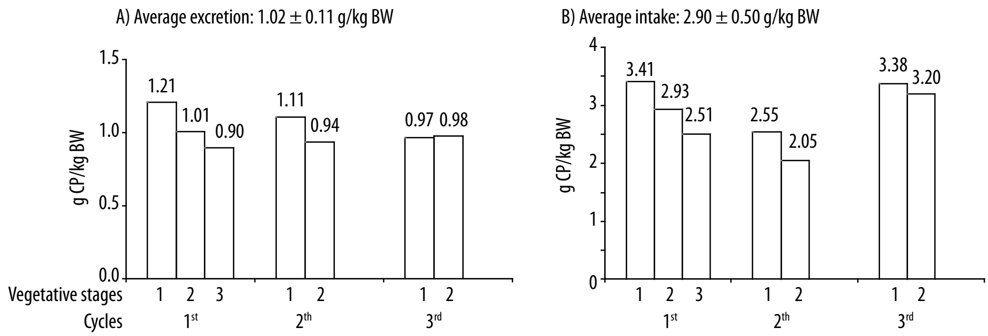

Figure 14.4. Intake and excretion of faecal nitrogen in adult light horses consuming fresh, natural meadow forage provided free choice at through throughout the grazing season (adapted from Chenost and Martin-Rosset, 1985; Martin-Rosset, unpublished data).

number of data obtained than for fresh forage. One can determine on one hand, the CP content of grazed forage by reading it from feed composition tables, if the cutting and stage of the forage is known (Chapter 16), or by chemical analysis of the forage. On the other hand, the quantity of dry matter ingested for which an estimate is given for the principal physiological states in Table 14.4 in order to calculate the CP intake quantity per kg of estimated or measured bodyweight (Chapter 2). However, faecal excretion decreases from 5 to 15% if the horse is supplemented with concentrate feed

Table 14.3. Estimation of faecal excretion (per kg BW) of total crude protein (g CP faecal) and total ash (g AS faecal) with the daily intake quantities (g/kg BW) of CP intake and AS intake in the horse consuming natural meadow grass hays (Martin-Rosset and Fleurance unpublished data).[1]

Equations	R^2	RSD	CV (%)
g CP faecal/kg BW = 0.331 + 0,256 (g CP intake/kg BW)	0.866	0.11	11.2
g AS faecal/kg BW) = 0.370 + 0.358 (g AS intake/kg BW)	0.548	0.16	16.3

[1] CP = N × 6.25; RSD = residual standard deviation; CV = coefficient of variation.

Table 14.4. Daily dry matter consumption: values provided are expressed in g/kg BW/d/al.

Adult bodyweight	Light breeds 500 kg	Draft breeds 700 kg
Physiological state		
Adult	20-21	23-34
Mare		
gestation	18-20	20-22
lactation	20-28	23-31
Young (1 to 3 years)	19-23	21-26

accounting for 10 to 30% (1 to 3 kg DM) of the total DM intake, as far as non-digestible CP (g/kg DM faeces) = 58 – 0.285 C (%) (Martin-Rosset and Dulphy, 1987).

The nitrogen excreted in faeces is made up of 85 to 95% of the proteins of which 57% are microbial in origin and 43% are endogenous proteins (mucous and digestive enzymes, Chapter 1) and the indigestible proteins of the plant cell walls (Chapter 1 and 12). Faeces contain only 5 to 8% ammonia nitrogen.

The daily quantity of faeces certainly varies with the type of animal being fed and its physiological state. As an indication, the weight of faeces produced by a mare in lactation that is currently on pasture is more than 35 to 40% greater than that of a mature horse of the same weight at maintenance. The mare's intake is very high at 90 to 160 g DM/kg $BW^{0.75}$ vs 75 to 115 g DM/kg $BW^{0.75}$ for the horse at maintenance (Chapter 1). The draft horse produces on average 15% more than the light horse per kilo of bodyweight while consuming similar forage based diet since the intake level of the draft horse, expressed per kilo of bodyweight is also higher (Martin-Rosset *et al.*, 1990).

The weight of faeces of the growing horse expressed per kilo of bodyweight is close to that of the mature horse at maintenance eating similar forage offered free choice since the quantities consumed are comparable: 97 to 108 g DM and 75 to 115 g DM/KG $BW^{0.75}$ respectively in young horses and adults at maintenance (Chapter 1, Table 1.5).

In practice, nitrogen content in consumed fresh forage and dry matter intake of forage expressed per kilo BW should be determined to implement the equation. The amount of nitrogen in the forage can be read from the feed composition tables (Chapter 16) if the cutting and vegetative stage of the forage are known or this information may be provided by a laboratory analysis. Dry matter quantities consumed are provided for information in Table 14.4.

Faecal excretion of minerals

The average total mineral content (or ash) of horse faeces fed as previously indicated during the same study (Table 14.2) is from 175±27 g/kg DM or 1.40±0.40 g/kg BW but with a very high coefficient of variation of 28.6%. Mineral content varies in fact with the cutting number but also within the cutting from 14 to 92%, no doubt in the case of last cutting in fall there is contamination of the grass with soil (Figure 14.5).

The daily excretion of minerals by horses is 701±177 g/d/al. throughout the grazing season (210 days) this represents a total output of 147 kg. The total daily excretion of minerals may be estimated using an equation with a moderate precision in adult horses only consuming fresh forages (Table 14.3). The effect of supplementing with concentrate feeds has not been evaluated, but it is reasonable to think that from observations made in stall feeding that it will not have much effect since concentrate feeds have a mineral content relatively close to that of forages.

The total daily quantity of minerals excreted in faeces varies similarly to that of nitrogen with the type of animal and the physiological state. Horse faeces are high in calcium and phosphorus and lower in magnesium, sodium and potassium (Table 14.5).

A 500 kg horse over the course of a total grazing season excretes about 10, 8, 2 and 2 kg respectively of calcium, phosphorus, magnesium and potassium. These average excretions vary as a function of the mineral content of the pasture forages, which are very variable (Chapters 12 and 16). Digestive interactions of the minerals themselves can also have an effect.

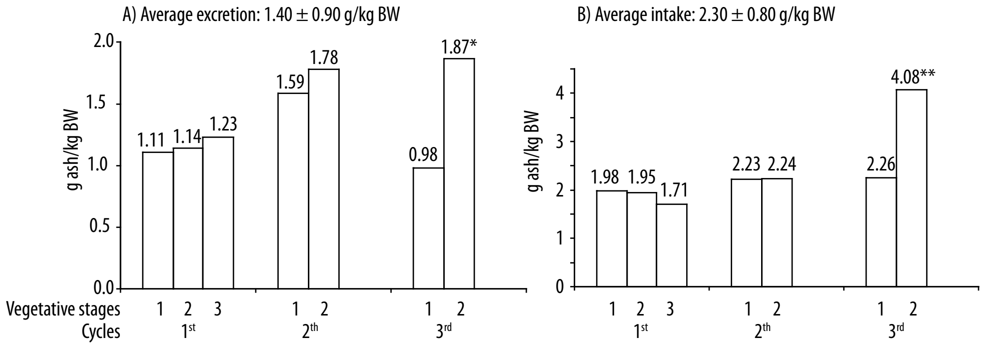

Figure 14.5. Total mineral (ash) intake and excretion in the light horse (stable-fed) (adapted from Chenost and Martin-Rosset, 1985; Martin-Rosset, unpublished data).

Table 14.5. Mineral content of faeces and urine of the horse (mg/kg BW) (Adapted from Hintz and Schryver, 1972, 1973; Meyer, 1979, 1980; Schryver *et al.*, 1970, 1971a,b; Van Doorn, 2003).

Minerals	Ca	P	Mg	Na	K
Faeces	90-100	75-85	15-20	8-30	15-25
Urine	40-50	20-25	5-15	10-30	125-150

The excretion of calcium in faeces increases as intake increases and, to a certain degree, with the intake of phosphorus as well. Phosphorus excretion increases as phosphorus and calcium intakes increase, but in the case of calcium only if the Ca/P ratio is not greater than 2.5-3.0. Magnesium excretion is increased by increasing intakes of magnesium, phosphorus and calcium. Faecal excretion of sodium decreases as potassium intake increases.

The daily quantities of various minerals that are excreted depend upon the type of animal and its physiological state.

Mineral digestibility coefficients are comparable between physiological states with the exception of potassium where it is much lower for the lactating mare and the young horse (Chapter 1, Table 1.14). It is necessary to take this characteristic into account when calculating an elimination balance for potassium by increasing by 20 to 30% the faecal content of potassium in lactating mares and young horses.

14.2.2.2 Urination

The horse at maintenance fed a forage based diet (45 to 90%) produces daily 12 to 25 ml/kg BW of urine, e.g. 6 to 13 l according to experimental measurements made on stalled light horses carried out at INRA. Quantities produced are certainly related to the amount of water consumed, which in turn is closely aligned with the dry matter intake (Chapter 1, Section 1.1.5; Chapter 2, Section 2.3). It is for this reason that requirements are expressed per kg of dry matter. It was shown some time ago that horses fed the same forage fresh or dry consumed respectively 30 and 2 l of water in the forage, but drank 18 and 40 litres. Total water intake was thus very similar. It is, therefore, reasonable to extrapolate the results obtained in stabled horses to those on pasture.

Excretion of urinary nitrogen

Urinary nitrogen excretion has only been measured in the same mature, stabled light horses fed conserved forages at trough during the same studies carried out at INRA to determine faecal excretion of nitrogen (Martin-Rosset *et al.*, 1984, 1990; Vermorel *et al.*, 1997). The nitrogen content of urine from a mature, 500 kg horse varied from 0.5 g N to 1.2 g N/kg $BW^{0.75}$ as the amount of nitrogen ingested increased from 0.7 to 1.7 g N/kg $BW^{0.75}$ on a diet based on preserved forage with or without supplemental concentrates according to balance studies conducted by INRA. Urinary nitrogen quantities excreted can be predicted using one of the two equations provided in Table 14.6.

Table 14.6. Prediction of daily urinary nitrogen excretion (mg N urine/kg $BW^{0.75}$) from amount of N ingested (g N intake/kg $BW^{0.75}$) on a diet of forage + concentrate (Vermorel, Martin-Rosset and Fleurance, unpublished data).[1]

Equations	R^2	RSD	CV (%)
mg N urine/$BW^{0.75}$ = 548.13 g N intake × $BW^{0.75}$ + 47.17	0.716	93.8	13.7
mg N urine/$BW^{0.75}$ = 6.04 g DMI × $BW^{0.75}$ + 94.91 CP (% DM) – 753.09	0.824	74.4	10.9

[1] CV = coefficient of variation; DMI = dry matter intake; RSD = residual standard deviation.

The 500 kg horse excretes from 53 to 80 g of nitrogen per day or 331 to 500 g of CP/d. Over the course of a pasture season of 210 days a horse will excrete 70 to 105 kg of total crude protein (N × 6.25 × 210) corresponding to 11-17 units of nitrogen fertiliser (70 or 105/6.25).

Excretion of urinary minerals

Horse urine is full of total minerals. It is very rich in potassium and contains much calcium. There are limited quantities of phosphorus and sodium and it is low in magnesium (Table 14.5). During a complete season at pasture a mature 500 kg horse will excrete about: 5.0, 2.5, 1.0, 1.5 and 14.0 kg of calcium, phosphorus, magnesium, sodium and potassium, respectively. These values are certainly plausible orders of magnitude but the mineral content of pasture forages varies between plant species and throughout the course of the season (Chapter 12 and 16). There are also interactions between minerals, which can have an effect.

The urinary excretion of various minerals in general increases with their intake level. In contrast the excretion of calcium decreases when the intake level increases. This is the reason that a Ca/P ratio of 1.5-2.0 in the diet should be maintained (Chapter 2). Magnesium excretion increases with increased intake of calcium but decreases with increased phosphorus intake. Sodium excretion decreases when potassium intake increases.

The urinary excretion of different minerals varies with their digestibility, as is the case with faecal excretion, namely for potassium (Chapter 1, Table 1.14).

14.2.3 Manure

14.2.3.1 Amount produced

All horses produce manure but about 60% of the million horses raised or used in France produce manure that must be handled and disposed of. This manure comes primarily from horses used in racing, sport, leisure and many ponies. Mares and their young are raised in box stalls or loose housing during the winter, while working horses are almost exclusively housed throughout the year in box stalls, with the exception of a small fraction of leisure horses and ponies. A growing population of working horses is concentrated in periurban areas: training facilities, which gather several hundreds of race horses. A high number (7,500) Equestrian Centres are also found in these areas. As an example, an average horse weighing 500 kg produces, annually, about 20 tonnes of manure (faeces + urine + bedding = manure). The total quantity of manure produced by the equine population is, therefore, in the order of several million tonnes. This approximation may also vary with the nature of the bedding: straw, flax, hemp, wood chips or wood fines.

Today, there are three major options for effectively using this resource in a techno-economic manner that is respectful of the environment: mushroom production, composting and energy production. All these processes and their possibilities are described in detail as are official controlling regulations of the Ministries of Agriculture, of the Environment and of Health (through DASS institution) and available in publications, which it is highly recommended to consult. There is a practical guide titled 'Better management of horse manure' edited by FIVAL in 2006 (www.fival.info). The practical guide titled 'Composting farm horse manure' edited by IFCE (www.ifce-haras-nationaux.fr) and 'Methanisation' or 'Combustion' edited by the cluster for equine competitiveness (www.cheval-fumier.com) are useful sources of information.

14.2.3.2 Major physical-chemical characteristics of manure

Manure has characteristics that vary with the amount of straw (or other bedding) which it contains, as well as the length and quality of storage (Table 14.7). The dry matter content, total nitrogen and the C/N ratio are quite different between manure with high straw/excreta ratio, e.g. 'strawy' and with low ratio but very well matured, e.g. 'stored'. Manure has high organic matter content as well as total nitrogen and is a rich source of phosphorus and potassium. The content of ammonia nitrogen is low.

Table 14.7. Chemical composition of manure and compost (FIVAL, 2006; IFCE, 2007).

Product type	Manure				Compost			
kg	'Strawy'	'Stored[1]'	Standard		Min	Max	Average	
	kg raw	kg raw	kg raw	kg dry	kg raw	kg raw	kg raw	kg DM
Dry matter	66.4	42.1	54.0	-	38.0	45.0	41.0	-
Organic matter	54.6	18.4	41.0	89.1	11.0	17.0	14.0	23.7
pH	7.6	8.0	-	-	7.7	8.0	7.7	-
N total	8.7	6.2	8.2	17.8	4.1	6.2	5.2	8.8
C/N	37.2	17.7	-	-	14.0	18.0	16.0	16.0
N ammoniacal	-	-	2.1	4.6	-	-	-	-
P_2O_5	3.7	3-	3.2	7.0	2.9	4.6	3.7	6.3
K_2O	17.0	12.2	9.0	19.6	5.4	10.3	7.9	13.4
MgO	-	-	2.0	4.3	-	-	-	-
CaO	-	-	-	-	7.7	16.4	12.1	20.5

[1] Stored for 2 months.

14.2.3.3 Value added techniques

Substrate for mushroom production

Until 1996, the production of white mushrooms (Champignon de Paris) was a major outlet for manure using 1,260,000 tonnes per year. Today this industry segment, which has undergone major restructuring, only uses about 500,000 tonnes (FIVAL, 2006).

Composting

Raw manure is seldom used as an agricultural application as it is low in fertiliser elements. Its transformation in the soil by micro-organisms releases considerable manure nitrogen, which otherwise is not available for cropping practices. Also, it can contaminate the soil with undesirable seeds considering the horse's digestion, or it may contain possible animal pathogens. Prior composting is much preferable.

The composting process consists of transforming the initial product, placed in rows, by microorganisms at an elevated temperature of 50 °C minimum for 10 to 12 weeks with 2 turnings spaced 4 to 6 weeks apart (IFCE, 2007). A major objective of the process is to attain a C/N ratio <30 and a composition useful in an agricultural process (Table 14.8).

The cost of producing and spreading compost is less than the cost of buying and spreading chemical fertiliser in an agricultural enterprise: 62 vs 89 €/ha (IFCE, 2007).

Energy production

Manure can be productively used in energy production either directly through burning or indirectly through methane production:

- Combustion. Heat is produced by burning the biomass in equipment adapted for the purpose. This is possible in manure with a straw or wood chipped base. The residue only contains ash (mineral matter) which amounts to 10-15% of the initial volume. Economic viability is discussed (FIVAL, 2006).
- Cogeneration. This is an intermediate process between combustion and methane production. It consists of burning manure in an incinerator attached to heat exchanger that will recover heat to produce energy in the form of steam or electricity. This process can be of particular interest in areas with a high concentration of horses to provide material to the cogeneration units from close proximity (FIVAL, 2006; Equine Competitiveness Cluster, 2000: www.pole.filiere-equine.com). This process can improve the environmental impact of the incinerators.

Table 14.8. agricultural value of compost (IFCE, 2007).

	N	P	K	Ca	Mg
Agronomic unit	5.2	3.7	7.9	12.1	1.6

- Methane generation. This process has the objective of producing renewable energy: methane and a valuable residue. It is biological process during which the biomass is degraded by microorganisms in the absence of oxygen. Anaerobic digestion produces a biogas that is mostly methane and a digesta containing N, P and K which represents 80 to 90% of the initial product. The methane is used to produce either heat or electricity while the digesta is valued as an organic soil additive. This process uses only manure with a straw base as manures with wood chips has much less methanogenic potential. (FIVAL, 2006; Equine Competitiveness Cluster, 2000).

14.2.4 Conclusions

Horses produce little methane. As opposed to ruminants, horses contribute little to gasses that have greenhouse effects. The horse over the course of the grazing season annually contributes 20 to 40 units of nitrogen of which 60% is from urine. These contributions are not well distributed around the pastured area and so should be corrected by an appropriate distribution of manure (Chapter 10). Minerals contributions are important from both faecal and urinary sources. These are also not evenly distributed around the pastured areas both qualitatively and quantitatively, which requires correcting especially in the case of nitrogen (Chapter 10). It is possible to anticipate while grazing with quite good to moderate precision required controlling distribution of total nitrogen and mineral excreta from the horse, via both faeces and urine, with the help of simple and common indicators. Unfortunately, the excretion of various minerals cannot be predicted with great accuracy, so prediction equations are not yet provided. Limiting their excretion evaluation to an average balance may be accomplished by using contents of minerals in faeces and/or urine published in the literature reviewed in this chapter as well as the quantities of faeces and urine provided in this chapter.

When the horse is housed in a stall, the nitrogen and minerals excreted are recovered in the manure. The growing volume of manure produced by horses requires the development of efficient transformational procedures for increasing manure value. These procedures exist. They must be rapidly implemented, especially in periurban areas where the number of horses in equestrian and training centres is increasing.

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Chapter 15. Behaviour and behavioural management during rearing and stabling

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The advancements in the behavioural sciences over the last three decades have highlighted the need for increased understanding of the behaviour of farm animals to promote their welfare as well as increase their performance.

Behavioural sciences are of particular concern when it comes to horses especially because of the important influence of management conditions on their development during their first four years of life (Chapters 3 and 5), as well as the management conditions for adult horses that can influence them throughout their lives (Chapters 2 and 6).

The goals of this chapter are:

- to describe the behavioural development of horses from birth to adulthood, in relation to their environment and management practices;
- to stress the need to preserve or to improve adult horses' living conditions in stables.

The descriptions and explanations of the observed behaviours include practical recommendations to optimise the behavioural management of adult as well as young horses.

15.1 Horses' natural environment

All populations of horses exhibit similar behaviour traits when living under natural conditions, as exemplified by feral horses (domestic horses that have been released in the wild) or Przewalski horses (true wild horses). They tend to live on home ranges (where all the group's activities occur) the size of which is dependent on the area that supplies sufficient resources to cover forage, water and shelter requirements, up to 200 km². Horses gradually shape their home range by creating trails (that they routinely follow in single file,) areas for defecation, and areas for rolling (Waring, 2003).

Foraging, their main activity, can account for 14 to 18 hours of their day (Chapter 1, Section 2.1). The main characteristics of their foraging are that it occurs while they are moving and that it is diverse: grasses, bush plants, aquatic plants, berries, etc. (Chapter 10). Horses even search actively to diversify their diet has been demonstrated experimentally (Goodwin *et al.,* 2005) and is very likely a way to satisfy various physiological needs. Horses live in harem-type groups with 1 to 2 stallions and 2 to 3 mares with their recent offspring; or in social groups of single non-breeding males (3 to 10 individuals) or 2-3 year old juveniles; or, although rarely, solitary stallions have been observed (Feh, 2005).

Generally, the predominant activities in a socially well-organised life based on affinities between individuals and knowledge of other members' status are foraging, resting and slow moving. Only in incidences of danger or during the reproductive season are there more rapid movement, vigilance, or sexual displays occurring.

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15.2 Behavioural development

In a natural environment, foaling occurs away from the herd and the foal spends the first 24-48 hours post-foaling only with the dam. The first suckling occurs very soon after birth, generally within 2 hours, although large individual variation can exist: from 30 minutes to 7 hours for a healthy foal. Passive transfer of immunity to the foal via intake of colostrum (mare's first milk) is only possible through the first 12-24 hours of life. Foals spend most of their time close to their mothers during their first weeks (90% of their time within 5 meters of their mother) and suckle frequently, nearly 60 times per day. As the foals grow older they gradually move farther away from their mothers and the daily suckling bouts decrease to less than 10 just before weaning, whereas the time spent grazing increases to 40% of their time-budget (Crowell-Davis and Weeks, 2005; Chapter 5, Section 5.4.1.2).

Weaning occurs over several months by a gradual increase of the distance between foal and mare, a decrease of suckling frequency, a change to a more varied diet, and the development of a larger social network. Weaning is initiated by the mother when foal is about 9 months old, that is, not long before the birth of the next foal. Mares that are not expecting a foal can continue to let the foal suckle for a longer period of time. In this case, the mare and foal may develop a close relationship and stay together until the foal is up to 2 years of age, although nursing may have ceased long before.

Foals may experience the diverse social organisation of a herd where they first interact with their mothers, then gradually with the other members of the herd: other juveniles of the same age or older, other mares whether related or not, and the stallion. This diverse social network is essential to the foal's behavioural development, and in particular, its development of social skills (Bourjade *et al.*, 2009).

15.3 Role of social influences and of individual experience on the development of foraging

In a natural environment, young horses must learn to eat suitable types of food, and therefore to discriminate, categorise (e.g. edible/toxic), find and identify them, that is, to associate a place or a visual cue with a resource, and this in a vast complex habitat.

Currently little is known about the development of their dietary selectivity. Of all the mechanisms suggested, transmission through maternal milk cannot be ruled out (see other species) and coprophagy (ingestion of faeces, their mother's in particular) has been thought to allow transmission of food preferences as well as absorption of bacterial flora and of protozoa adapted to fibre digestion (Crowell-Davis and Houpt, 1985). In addition, foals generally graze along with their mothers and from this they can observe the appropriate foods to select (type of plant, part of the plant, state of development of the plant, etc.). The dam is the first role model whose behaviour influences largely, and for a long time, the relationships of the foal with its environment (Henry *et al.*, 2005, 2007). Nothing is known about other possible social influences on the development of food preferences. Overall, all the experiments aimed at verifying learning by observation (horses observe an individual trained to perform a task: for example, open a box containing food) have failed, because it seems that the observer's attention is drawn towards the spot where the device is placed rather than how to get to it (Clarke *et al.*, 1996). This type of focus on a specific location makes sense under natural conditions where knowledge of the places where resources can be found could be passed on by the experience of other individuals.

Nevertheless individual experience remains important and various experiments have shown that horses are able to discriminate visual cues (e.g. geometrical shapes) reinforced by food, to categorise shapes, sizes or types of stimuli, and memorise this learning for a long time (6 to at least 10 years). Learning is easier when each stimulus is associated with a different food type (e.g. carrots/apples), indicating that horses associate a given cue with a resource, no doubt a major process for acquiring competences in the field.

In addition, a recent report showed that if a foal is faced with either congruent or non-congruent visual and spatial information concerning the location of food, they prefer to act on the basis of the spatial information (Hothersall *et al.,* 2010). Therefore, horses first learn to locate resources in a space, and then learn to discriminate food items more subtly. At this stage, they can associate food characteristics with post-ingestion consequences, and can develop conditioned food aversions, as demonstrated experimentally, which is a mechanism enabling them to learn to avoid toxic plants. However, it would seem that the learned behaviour is effective only if the injection (apomorphine) occurs just after ingestion of the food item, and is not a very effective mechanism for substances with delayed action. Horses certainly use all these mechanisms to select appropriate plants and to ensure the diversified diet observed in the field and actively searched for by horses in a domestic environment.

15.4 Impact of breeding practices on behavioural development

The conditions of development of young horses in a domestic environment differ greatly from those in a natural environment: there are interferences during foaling, precocious simultaneous feeding and social weaning, keeping of young in same-age and same-sex groups. It seems every human action has an impact experienced subjectively more or less positively by the animals. For example, the practice of helping a foal finds the teat by hand has repercussions on the foal's behavioural development: such as, excessive attachment to its mother, and little play and interaction with other foals (Hausberger *et al.*, 2007). In addition, this interference by humans does not generally accelerate food intake: if suckling occurs too soon after birth a foal can have difficulties holding onto the teat and difficulties with the mare not allowing her foal to suckle. Similar results have been reported for bottle-fed foals.

Other more intensive practices at birth, such as 'the imprinting of newborn foals' largely promoted in the recent past, have effects that are both negative and lasting. This method recommended handling newborn foals all over their body and exposing them to different stimuli (halter, clippers, etc.) that they would have to face later in life all within the first few hours of life. In fact, not only did this manipulation not have the effects hoped for (it did not improve contact with humans or objects), but it induced short-term adverse effects including developmental delay (1^{st} suckling delayed,etc.), abnormal behaviour (sucking various substrates); and the medium- and long-term effects included excessive attachment to mother associated with a delay in eating solid food and social withdrawal from other foals. Consequently, foals also took longer to recover from the stress related to weaning (Henry *et al.*, 2009).

Another key stage in a domestic situation is weaning that is not just a food-transition stage but also a social separation stage. Weaning on breeding farms generally consists of abruptly separating the foal from its mother and generally occurs when the foal is between 4 and 6 months old (Chapter 5, Section 4.1.2.3). In addition to the well-known behavioural modifications observed during the first days following weaning (vocalisations, increased locomotion, aggressiveness, etc.), and the associated risks (injuries, falls, etc.), delayed growth and loss of weight have also been reported.

Redirected suckling (of herd mates, for instance), wood chewing (lignophagia) and/or biting herd mates are frequently observed just after weaning. It was estimated that 10% of 225 foals observed had started cribbing one month after being weaned, 30% had developed lignophagia at 3 months and 5% motor stereotypies at 10 months (Waters *et al.*, 2002). Two aspects of human practices influence the emergence of abnormal behaviours: feeding and rapid social transition.

At the social level, the impact of weaning varies relative to the method applied (Waran *et al.*, 2002). The one with the most negative effects involves repeated separations from mother before weaning (to 'habituate' the foal) that appears to sensitise foals to separation stress, while abrupt separation from the dam occurs on weaning day. Alternative methods, such as gradual withdrawal of mares from the group, reduce the stress level. The best approach identified at present is the introduction of experienced adult horses to a group of weanlings, which helps to reduce separation anxiety, the expression of non-nutritive suckling and the emergence of abnormal activities (Henry *et al.*, 2012). At the minimum, weaning foals as a group in a paddock facilitates a more rapid return to normal activity than social isolation in a box stall. The least appropriate method is clearly the individual confinement of foals in box stalls and fed a diet that is predominately concentrate feed.

Concurrently, particular attention must be given to the diet, as a rapid transition to concentrate feeds can induce the development of stereotypies and gastric disorders. Therefore, it is important to provide young horses with a mixed diet including plenty of forage before weaning to facilitate the transition to a solid diet and to limit post-weaning weight loss (Waran *et al.*, 2002; Chapter 5, Section 5.4.1.3 and 5.4.2). Foals that have been given a high fat and fibre diet both before and after weaning are less stressed immediately after weaning than foals that have had a high starch and sugar diet, and are calmer in other situations (Nicol *et al.*, 2005).

The presence of adults is also beneficial for their social development in subsequent stages of growth. The addition of adults into groups of yearlings and 2 year olds improved herd cohesion and kept the groups less excitable, reducing the possibility of accidents occurring (Bourjade *et al.*, 2008). In addition, the horse's strong motivation to forage helps facilitate different aspects of human/young horse relationship. Simply by repeatedly exposing young horses to humans providing hay helps to facilitate positive contact with 2-year-old horses. Using food as reinforcement for learning tasks or for recompensing invasive care is a good way to obtain both rapid progress and a good relationship as well as to reduce the adverse effects of invasive routine handling (Sankey *et al.*, 2010).

15.5 Adult horses in stables

Domestic horses are most often housed in small box stalls, with reduced daily turnout and a diet composed mainly of concentrate feed and dry roughage distributed in a limited number of meals.

These conditions induce many abnormal behaviours such as stereotypies (windsucking, weaving, etc.) that can affect between 5.2 and 32.5% of a population (Parker *et al.,* 2008; Waters *et al*., 2002). Other abnormal and also described as undesirable activities (pawing or licking walls or bars) can become stereotypic and have been observed in young horses housed in box stalls in contrast to horses kept on pastures. Not only can these abnormal behaviours be considered as indicators of poor welfare but they can have significant consequences for the owner by diminishing the animal's performance and/or the price it would fetch in a sale. Once these stereotypies have developed, they are difficult to eradicate, and may even become irreversible. It is strongly recommended not to try to attenuate them by coercive methods like cribbing collars, elimination of surfaces to grasp or door bars. This only adds to the stress and accentuates their poor state of welfare. The only way to avoid the development of stereotypies is therefore prevention.

For practical reasons, not all horse owners desire to leave their horses permanently on pasture with a herd, although this would be ideal. Therefore, in order to prevent the development of stereotypies and to increase the horses' well-being in box stalls, different types of enhancements to the environment can be used. They involve nutrition, social environment, the structure of the buildings or providing various sensory stimulations.

Types of enhancements through feeding would be to increase the time horses spend eating and at the same time stimulate their taste senses. In order to do this it is possible to vary the taste and formula of meals or to use devices to distribute the food gradually and in different parts of the box stall (Goodwin *et al.,* 2005, 2007). It is possible to hang several hay nets instead of only one or hide food under straw rather than in the feeder. Thus, horses can express the foraging behaviour they would perform in their natural environment where they move from one food source to another.

Social enrichment allows horses to be in contact with other horses. Several reports show that maintaining horses in groups, during both the weaning and training periods helps limit aggressive interactions with humans and the development of abnormal behaviours (Heleski *et al.*, 2002; Parker *et al*., 2008; Sondergaard and Ladewig 2004; Waters *et al*., 2002). Even though for convenience and by tradition many owners prefer their horse housed in an individual box stall so that it is conveniently available, it is not necessary to keep the horse there permanently. It is much better to bring horses to the stable only when they are to be used, during the day for example, and to turn them out the rest of the time out on pasture with other horses.

The environment of the box stall is important. First, a large area encourages the horse to take more time for resting (Raabymagle *et al*., 2006). Bedding must also be taken into consideration: horses are more likely to lay prone in straw than in shavings (Pedersen *et al*., 2004). In addition, straw allows horses to spend more time foraging and decreases the frequency of stereotypic behaviours. Further, it is suggested to add various sensory stimulations to the environment. Different types of objects can be hung in the box stall or put on the ground, like balls or logs (Lansade *et al*., 2014). These objects encourage temporary exploration. However, it is important to change these objects regularly so that they remain interesting otherwise they are of no use. Brushes can also be attached to the walls so that horses can scratch themselves, an activity that is impossible when all the walls are smooth. Adding scents by putting a few drops of essential oils on the above-mentioned objects can help stimulate olfaction. Some scents like rose or chamomile are supposed to have a calming effect (Wells, 2009). Finally, playing music is suggested to decrease stress (Houpt *et al*., 2000).

All these enhancements aim at enabling horses to express a maximum of activities that they would perform in their natural environment, and to reduce time spent unoccupied. Besides an effect on their well-being, they also are suggested to limit dangerous behaviour towards humans and reduce horses' emotional reactivity and improve learning abilities (Lansade *et al.*, 2014). Nevertheless recent studies seem to indicate that artificial types of enhancements (e.g. toys) are of little effect once the first interest is gone. Food related items, and especially roughage are by far the most efficient and 'natural' way of dealing with the unnatural domestic conditions (Jorgensen *et al.*, 2011).

15.6 Conclusion

The conditions offered to most domestic horses at all stages of their development are far removed from their natural living conditions in the wild, and this would not be of major importance if no associated 'deviances' were observed. However, these deviations from normal behaviour do exist ranging from visible behavioural deteriorations (stereotypies that can affect up to 60-80% of the horses on some sites), aggressiveness towards other horses and/or humans, to physiological disorders (gastric ulcers, for example). Besides the spatial restriction mentioned above due to confinement, other categories of problems can be identified: social restrictions and various social stresses, including in particular that related to weaning, human actions (at birth, at work, during routine care), but also and in a very central way, nutritional aspects. Besides an association that has become gradually clearer between lack of roughage and an excessive proportion of energy-rich concentrated food and the emergence of stereotypies, and this from a very young age, the temporal distribution of food, the availability and the variety of roughage provided are important. A recent study illustrates the major impact on horses of their feeding behaviour. A study of brood mares in paddocks without grass showed that these mares had intense locomotive activity, that their few social interactions were antagonistic by nature and that their reproductive performances were poor. Simply changing the temporal pattern of feeding by providing hay nets while they were in the paddock (6 h) had a major impact: aggressive behaviour decreased, social cohesion increased, intense locomotion (and therefore loss of energy) decreased, 'comfort' activities emerged, body condition improved as well as reproductive performance (Benhajali *et al.*, 2008, 2009, 2013).

Feeding practices are therefore crucial, and their impact has often been underestimated. The discussion needs to continue on the enhancement of what should be the basis of good husbandry: diversified roughage (hay) provided continuously and predominately? A simple well thought-out vision of horses' fundamental requirements should be sufficient to guarantee them a decent life.

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Chapter 16. Tables of chemical and nutrient composition of feedstuffs

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16.1 Construction of the tables

The tables display 240 temperate zone feeds: 169 of which are forages, roots and tubers, and 71 are ingredients.

16.1.1 Forages

The chemical composition and nutritive value of each forage species are given in relation to vegetation stage, for the first growth and according to age of regrowths.

16.1.1.1 Vegetation stages and preservation system

The tables provide all the possible stages at which forages are used either fresh or after preservation. The same presentation according to growth stage or age has been adopted for preserved forages, but with data referring to the usual stages or ages for hay or silage preparation. In addition, for each stage, the preservation system which may alter feeding value has been taken into account: barn drying or field curing, climatic conditions during haymaking, wilting or harvesting by direct cut for silages.

The main by-products of field crops: cereals straw untreated or ammonia treated, pea straws are also included.

16.1.1.2 Chemical composition

The data on forages come from measurements of chemical composition, and digestibility trials carried out at INRA on horses only or simultaneously on ruminants.

The content of ash, crude protein, crude fibre, cell wall content (NDF, ADF and ADL) and gross energy from INRA (INRA, 2007) tables of feeds for ruminants to permit end-users to feed the same forages to both horses and ruminants when they are managed on the same farms. As result, the chemical characteristics come from data obtained on samples of forage materials exclusively analysed in the laboratory of the INRA research center of Clermont-Ferrand/Theix, where the tables for horses were established. The dry matter content of silages that are given is corrected for losses of volatile compounds during oven drying (Chapter 12, Table 12.2).

The content of lysine of grasses silages and hays was estimated using a relationship between lysine and crude protein content determined in such forages established by Martin-Rosset and Andueza (unpublished data).

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Silages (grasses or mixed grasses and legumes at different stages of maturity):

Lysine (%DM) = 0.051CP (%DM) – 0.240
SE_y=0.05 R^2=0.832   n=10

Hays (grasses, legumes and mixed grasses and legumes at different stages of maturity):

Lysine (%DM) = 0.060CP (%DM) – 0.304
SE_y=0.08 R^2=0.864   n=18

16.1.1.3 Digestibility determination

Digestibility was determined at INRA, Centre of Clermont-Ferrand/Theix using total faeces collection (TFC) with the same 6 adult horses aged between 4 to 12 years weighing 502±27 kg. The horses were fed forage based diets near maintenance (1.2 times INRA maintenance requirement to take into account the individual variability of requirements, see Martin-Rosset and Vermorel 1991) as there is no effect of feeding level on digestibility of forages (Martin-Rosset and Dulphy 1987; Martin-Rosset *et al.* 1990), because there is no significant influence on mean retention time (Miraglia *et al.,* 1992). Straw-based diets were only supplemented with nitrogen and minerals to meet the requirements of horses and allow normal digestion in the large intestine (Glade, 1983, 1984).

Each measurement period lasted 6 days preceded by an adaptation period of 14 days (Martin-Rosset *et al*., 1984, 1990). However, determinations of digestibility of fresh forages were carried out continuously during each cycle of growth after an adaption period of 7 days followed by a measurement period of 6 days separated by one day only (Sunday) (Chenost and Martin-Rosset, 1985).

For each digestibility trial, representative samples of the forage fed to animals, eventual refusals and corresponding faeces were analysed to determine gross energy, ash, crude protein (6.25× N Kjeldhal), crude fibre and cell wall fraction content (NDF and ADF).

Digestibility of 33 forages (fresh forages: natural grassland and legumes; 19 hays: natural grassland, grasses and legumes; and 2 cereals straw: wheat and barley) was determined simultaneously in horses and sheep according to the same protocols designed previously. The following relationships were calculated for fresh forages and hays to predict digestibility of organic matter in horses (OMd_H) from that in sheep (OMd_S) or digestible crude protein in horses (DCP_H) from that in sheep (DCP_S) (Martin-Rosset *et al*., 1984, 1994).

Natural grassland and grasses:

OMd_H (%) = -14.91 + 1.1544 OMd_S (%)   RSD=2.3 R^2=0.960 n=18

Legumes:

OMd_H (%) = -9.94 + 1.1262 OMd_S (%)   RSD=2.6 R^2=0.710 n=15

The digestibility of organic matter is lower in horses than in sheep, by 3.3 to 6.4 points for grasses and natural grassland and 2.4 points for legumes: the lower the digestibility, the larger the difference between animal species. These relationships were used to predict OMd_H of 170 forages from OMd_S obtained with sheep (INRA, 2007). As result, the tables provide the nutritive value of a larger panel of forages and vegetation stage or preservation methods. For protein the following relationships were calculated:

Green forages:

Horse: DCP_H (g/kg DM) = -44.32 + 0.9645 CP (g/kg DM) RSD = 7
R^2=0.978 n=18

Sheep: DCP_S (g/kg DM) = -43.89 + 0.9438 CP (g/kg DM) RSD = 4
R^2=0.990 n=18

Hays (grassland, grasses and legumes):

Horse: DCP_H (g/kg DM) = -37.94 + 0.9053 CP (g/kg DM) RSD = 9
R^2=0.951 n=19

Sheep: DCP_S (g/kg DM) = -34.08 + 0.8716 CP SD = 8
R^2=0.964 n=19

The digestible crude protein content of green forages or hays predicted in horses and sheep using the equations calculated in each animal species were similar: less than 5% DCP difference whatever the categories of forages. To date, the equations designed for horses were used to estimate the DCP content of all forages.

In addition, digestibility trials were carried out at INRA to determine OMd and MADC content of silages (grass and maize), dehydrated forages (lucerne) and by-products such as straws of mature cereals (native or ammonia treated) and of grasses or legumes seeded for plant breeding. Data concerning roots and tubers come from publications and a few INRA determination.

16.1.1.4 Energy and protein value

The energy and protein values of forages were calculated using the step-wise procedure of UFC and MADC systems (Chapters 1 and 12), which is the reference procedure to be used to establish tables.

16.1.2 Concentrates: ingredients and agro industrial by-products

The chemical composition and the nutritive value of each concentrate are given in relation to the native or processed status according to the types of feed materials.

16.1.2.1 Chemical composition

The content of ash, crude protein, lysine, crude fibre, cell wall fractions (NDF, ADF and ADL), ether extract, starch and gross energy come from INRA-AFZ tables of composition and nutritive value of feed materials for farm animals including horses. The chemical characteristics are drawn from data obtained on samples of feed materials analysed in the laboratories of feed companies in France and Western Europe. The components content were determined using methods that are recommended by official organisations in France (ISO and AFNOR) and by other institutions (European Commission and AOAC) (Chapter 12, Table 12.1 and further reading: feed analysis). Original data were validated at the source to discard data obtained with atypical methods. Consistency of chemical composition was verified by comparing related components content.

16.1.2.2 Digestibility determination

The digestibility was determined at INRA with TFC using the same horses previously mentioned fed at maintenance. Each unique or successive periods of measurement lasted 6 days following 7 or 14 days adaptation period depending on the proportion of concentrates in the diet and the experimental design: Latin square or not. For each digestibility trial representative samples of concentrates and forages fed to animals, eventual refusals, and corresponding faeces of the diet studied were analysed according to the description given previously for forages, including starch. The database was increased with the inclusion of the data obtained in horses by the Research Centre of Lelystad (the Netherlands) according to the same procedure used at INRA (Smolders *et al.*, 1990) in the scope of a collaboration agreement, and a few data published in the literature.

The digestibility coefficients were determined using:

- either the regression method for energy rich feeds when concentrate proportion in the diet ranged between 0 to 60 or 90% depending of the type of forage based diet according to the methodology described by Martin-Rosset and Dulphy (1987);
- or calculated by difference for protein rich feeds: cereals by-products, oils and legumes seeds and their by-products when concentrate proportion in the diet ranged between 30 to 40% only to take care of the health of horses (Martin-Rosset and Dulphy, 1987).

No feeding level influence or associative effect was considered in the calculation of digestion coefficients according to Martin-Rosset and Dulphy (1987) (Chapter 12).

16.1.2.3. Energy and protein value

The energy and protein values of concentrates were calculated using the step-wise procedure of UFC and MADC systems (Chapter 1 and 12), which is the reference procedure.

16.1.3 Minerals and microminerals content

Calcium, phosphorus and magnesium content are only displayed in the tables for forages and concentrates. For forages they are only indications, especially since they may be modified by environmental conditions such as soil type, extent and nature of fertilisation (Chapter 10,

Figure 10.11) and weather. For concentrates they may also be affected by origin and processing. Additional information is also given in Chapter 12, Tables 12.21-12.24.

16.1.4 Vitamins

Vitamins A, D, and E contents are only indicated in appendix 2 in this chapter. One should keep in mind that their content may change for forages with harvest methods and conditions (Chapter 11, Section 11.2, Figure 11.4) and for concentrates with origin of materials, technological process and conditions of conservation.

16.2 Presentation of the tables

These tables list the main feedstuffs available for feeding equines: forages and ingredients. They display:
- the chemical composition of feedstuffs: content of the main components required for appraising or (and) predicting their nutritive value;
- the energy and nitrogen values essential for calculating the rations of horses.

In addition there are annexes, which provide the content of some components necessary to ensure the nutritional balance of rations. The energy and nitrogen values:
- of the forages which are different from previous INRA tables (INRA, 1990), even though the chemical composition is similar because they include advances in INRA systems which result in a decrease of energy value and a larger diversification of nitrogen values (Chapters 1 and 12);
- of the ingredients and their by-products are different, especially the nitrogen values which include advances in knowledge concerning nitrogen digestion (Chapters 1 and 12).

16.2.1 Classification of feedstuffs

Types of feedstuffs	Code	Numbers	Pages
Forages			
Green forages	FV		
Natural grasslands		FV0020 to FV0220	522-523
Grasses		FV0410 to FV1390	524-527
Legumes		FV2120 to FV2400	524-527
Silages	FE		
Natural grasslands		FE0490 to FE0990	528-529
Grasses		FE1580 to FE4140	530-533
Whole crop cereals		FE4710 to FE4770	532-533
Hays	FF		
Natural grasslands		FF0010 to FF0580	534-537
Grasses		FF1060 to FF2730	536-543
Legumes		FF3220 to FF3660	542-545
Straws, lignified forages	FP	FF0020 to FF0160	546-547
Roots, tubers	FR	FR0010 to FR0040	548-549

Types of feedstuffs	Code	Numbers	Pages
Ingredients			
Dehydrated and agglomerated	CD	CD0020 to CD 0090	550-551
Cereals	CC	CC0010 to CC0100	550-551
Cereal by-products	CS	CS0010 to CS0250	552-553
Other plants by-products	CF	CF0010 to CF0200	554-555
Fat	CG	CG0040	554-555
Oilseed meals	CX	CX0010 to CX0170	554-555

The codes are the same as those used in the INRA tables (Agabriel, 2007) for ruminants. The codification of all the feeds is not always continuous within the same category of feeds because all the feedstuffs in tables for ruminants are not included in tables for horses. Those codes are the same as those used in the software 'EquINRAtion'

16.2.2 Terminology and symbols used

DM	Dry matter content of feeds (%)
UFC	Energy value expressed in 'horse feed unit' (UFC/kg)
MADC	Protein value expressed in 'horse digestible crude protein' (g MADC/kg)
OM	Organic matter content (g/kg)
CP	Crude protein content (N × 6.25) (g/kg)
CF	Crude fibre content (Weende) (g/kg)
NDF	Neutral detergent fibre content (total cell wall) (g/kg)
ADF	Acid detergent fibre content (lignin-cellulose) (g/kg)
ADL	Acid detergent lignin content (lignin) (g/kg)
EE	Fat content (ether extract) (g/kg)
Starch	Starch content (g/kg)
OMd, CPd, Ed	Digestibility coefficients of OM, CP, and energy (%)
P	Phosphorus content (g/kg)
Ca	Calcium total content(g/kg)
Mg	Magnesium content (g/kg)
GE	Gross energy content (kcal/kg)
DE	Digestible energy (kcal/kg)
ME	Metabolisable energy content (kcal/kg)
NE	Net energy content (kcal/kg)

16.2.3 Definition of the vegetation stages

16.2.3.1 Grasses and natural grasslands at the first cycle

Early grazing: the base of the ear of the grass, or most representative grass species (natural grassland), is situated within the leaf sheath at a height less than 7 to 10 cm above the tiller base.

Grazing stage (natural grasslands): the base of the ear is within the leaf sheath, 7 to 10 cm above the tiller base.

- 10% ear emergence: the ear emerges from the leaf of the sheath; normally 5 to 10% of the plants observed in a one metre row have visible ears.
- 50% ear emergence: ear emergence has occurred for 50% of plants in a one metre row.

End of heading: ear emergence has occurred for 90% of plants in a one metre row.
Beginning of flowering: 5 to 10% of plants show visible stamens.
End of flowering: most plants present visible stamens.

16.2.3.2 Grasses and natural grasslands at the following cycles

Fresh forages – silages

- Second regrowth
  - Vegetation stage: leafy.
  - Number of weeks following 1st growth at 50% ear emergence for natural grasslands:
    - fresh forages: 5 or 6 weeks;
    - silages: 6 or 7 weeks.
  - Number of weeks following 1st growth at heading for grasses:
    - silages: 7 weeks.
- Third regrowth (for fresh forages)
  - Vegetation stage: leafy.
  - Number of weeks following 2nd cycle for fresh forages:
    - natural grasslands: 6 weeks (lowlands) or 7 weeks (uplands);
    - grasses: 6 weeks.

Hays – natural grasslands and grasses (temperate zone)

- Second regrowth
  - Vegetation stage: leafy for natural grasslands and grasses, but stemmy sometimes for grasses.
  - Number of weeks following 1st growth at 50% ear emergence for:
    - natural grasslands: 6 weeks (uplands) or 7 weeks (lowlands);
    - grasses: 7 weeks.
  - Hays – natural grasslands (Mediterranean zone: irrigated)

Three dates of cutting according to irrigation conditions.

16.2.3.3 Cereal plants crops

- Stem elongation: no ear emergence from the leaf sheath.
- Flowering: silks (corn or maize) or stamens (other cereals) visible on 50% of plants.
- Milk stage: the grain has developed its final form and is filled with a milky liquid.
- Dough stage: the grain is coloured, easily squashed between fingers and its content forms a paste.
- Flint stage: the grain has a horny covering; it is hard although it can still be scratched.

16.2.3.4 Legumes at the first cycle

- Vegetative stage: no floral buds visible.
- 10% bud stage: appearance of flowering buds; 5 to 10% of stems examined in a one metre row have flowering buds at their tip.
- 50% bud stage: 50% of stems examined in a one metre row have flowering buds at the tip.
- Beginning of flowering: 5 to 10% of stems examined in a one metre row have at least one open flower.

16.2.3.5 Legumes at the following cycles

Fresh forages

- Second regrowth
  - Vegetation stage: stemmy.
  - Number of weeks following 1st growth at 50% bud: 5 or 6 weeks.
- Third and fourth regrowth
  - Vegetation stage: stemmy.
  - Number of weeks following 2nd growth: 5 or 6 weeks.

Hays

- Second regrowth
  - Vegetation stage: stemmy.
  - Number of weeks following 1st growth at 10% or 50% bud according drying techniques, barn-dried or field-cured, respectively: 7 weeks.

16.2.4 Technological processing of feedstuffs

The feedstuffs which are displayed in the tables correspond to:

- unprocessed feeds: green forages (Chapters 9 to 12);
- feeds harvested using classical or modern machines and conserved: silages, hays, dehydrated forages according to the processes described in Chapter 11;
- by-products of plant culture and harvest (Chapter 9);
- ingredients (raw materials) harvested from mature plants: grains and native seeds, or processed to be incorporated in compound feeds (Chapter 9).

The effects of processing on chemical composition and nutritive value have been extensively described in Chapters 9, 11 and 12. The nutritive value displayed in the tables corresponds to processed feedstuffs:

- for forages: silages, haying, dehydration;
- for the ingredients: cereals subjected to mechanical or thermal processes (with the exception of oat which is native);
- by-products of cereals: resulting from grains subjected to mechanical processes by the milling and starch industries;
- oil meals extracted by mechanical or chemical processes;
- other plants by-products provided by industry;
- fats of plant origin provided by oil industry.

16.3 Appendixes

The tables have different appendices which list:

- the content of microminerals and vitamins of forages (Appendix 16.1 and 16.2);
- the inorganic sources of minerals to supplement the rations (Appendix 16.3);
- the sugar, starch and ether extract content of forages which may be used as variables in the equations for prediction of energy value (Appendix 16.4 and 16.5);
- finally, the fatty acid composition of the main vegetable oils, which can be used in diets of horses undergoing strenuous exercise (Appendix 16.6).

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Code INRA	**Fresh forages**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Natural grassland, lowlands (Normandy)								
First growth (a)								
FV0020	05/10 grazing stage	16.6	0.76	107	4,399	3,037	2,574	1,704
			0.13	18	69			
FV0030	5/25 10%ear emergence	17.2	0.69	76	4,410	2,804	2,419	1,556
			0.12	13	64			
FV0040	6/10 50%ear emergence	20.2	0.61	60	4,438	2,530	2,216	1,374
			0.12	12	57			
FV0050	6/25 flowering	19.2	0.53	47	4,413	2,226	1,969	1,185
			0.10	9	50			
2nd growth								
FV0100	leafy regrowth 5 w.	18.4	0.72	146	4,511	2,966	2,481	1,617
			0.13	27	66			
FV0110	leafy regrowth 7 w.	18.8	0.69	95	4,434	2,819	2,407	1,543
			0.13	18	64			
3rd growth								
FV0130	leafy regrowth 6 w.	15.7	0.70	134	4,477	2,895	2,434	1,576
			0.11	21	65			
Natural grassland, Mid Mountains (Auvergne)								
First growth								
FV0160	05/25 grazing	16.7	0.79	99	4,379	3,119	2,638	1,773
			0.13	17	71			
FV0180	6/25 50%ear emergence	20.4	0.61	60	4,387	2,501	2,186	1,363
			0.12	12	57			
FV0190	07/10: flowering	21.7	0.50	46	4,304	2,124	1,874	1,131
			0.11	10	49			
2nd growth								
FV0200	leafy regrowth 6 w.	18.5	0.72	137	4,453	2,929	2,436	1,616
			0.13	25	66			
3rd growth								
FV0220	leafy regrowth 7 w.	19.6	0.69	111	4,356	2,817	2,367	1,556
			0.14	22	65			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
889 74	172 69		244	525	280				4.0	6.0	1.9
906 68	133 64		272	550	303				3.8	5.6	1.9
921 61	109 61		313	587	336				3.6	5.2	1.9
922 54	92 57		335	606	354				3.6	4.7	1.9
897 71	215 76		267	545	299				4.0	6.9	2.2
903 68	155 68		272	550	303				3.8	6.9	2.2
895 69	201 74		269	547	300				4.0	6.0	2.4
905 76	166 67		224	485	247				2.7	5.1	2.3
928 61	111 61		304	583	331				1.8	4.5	2.2
917 53	92 56		323	595	344				1.5	3.5	2.2
905 71	209 73		229	512	263				2.4	7.0	2.2
895 69	179 69		230	549	278				2.7	7.0	3.1

Code INRA	Fresh forages	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Grasses, Ita. ryegrass none alternative								
Full harvest year, First growth								
FV0410	grazing stage	15.8	0.78	97	4,243	3,069	2,575	1,759
			0.12	15	72			
FV0440	50% ear emergence	17.8	0.62	37	4,180	2,520	2,203	1,400
			0.11	7	60			
Full harvest year, 2nd growth								
FV0490	stemmy regrowth 6 w.	17.6	0.61	91	4,252	2,517	2,154	1,362
			0.11	16	59			
Full harvest year, 3rd growth								
FV0520	leafy regrowth 6 w.	20.3	0.70	91	4,253	2,844	2,407	1,585
			0.14	19	67			
Grasses, perennial ryegrass								
Full harvest year, Late flower 1st grow.								
FV0690	grazing stage	17.2	0.79	92	4,197	3,127	2,654	1,784
			0.14	16	75			
FV0720	50% ear emergence	19.8	0.63	40	4,183	2,568	2,262	1,413
			0.12	8	61			
Full harvest year, 2nd growth								
FV0810	leafy regrowth 6 w.	20.3	0.75	112	4,282	3,003	2,523	1,677
			0.15	23	70			
Full harvest year, 3rd growth								
FV0860	leafy regrowth 6 w.	16.6	0.70	108	4,283	2,863	2,417	1,584
			0.12	18	67			
Grasses, tall fescue								
Full harvest year, First growth								
FV1070	grazing stage	20.0	0.65	101	4,162	2,646	2,248	1,463
			0.13	20	64			
FV1100	50% ear emergence	20.9	0.56	60	4,131	2,310	2,015	1,251
			0.12	12	56			
Full harvest year, 2nd growth								
FV1150	leafy regrowth 5 w.	20.8	0.64	98	4,173	2,653	2,254	1,451
			0.13	20	64			
Full harvest year, 3rd growth								
FV1180	leafy regrowth 6 w.	17.7	0.64	101	4,125	2,622	2,227	1,429
			0.11	18	64			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
886	168		188	450	215				3.0	4.3	1.4
77	64										
903	88		265	514	292				2.3	4.3	1.4
65	46										
895	150		276	570	308				3.0	4.8	1.4
64	67										
893	156		228	476	239				3.0	5.2	1.4
72	65										
880	157		227	511	255				3.7	5.7	1.5
80	65										
904	87		305	595	327				2.7	5.2	1.5
66	51										
890	180		230	519	257				3.7	6.2	1.7
75	69										
893	173		240	535	266				4.1	6.2	1.7
72	69										
869	165		247	550	278				3.0	3.8	1.5
68	68										
883	111		295	594	321				2.7	3.3	1.5
60	60										
873	161		256	543	284				4.1	4.8	2.0
68	68										
861	164		260	546	279				3.4	5.7	2.0
68	69										

Code INRA	**Fresh forages**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Grasses, cocksfoot								
Full harvest year, First growth								
FV1240	grazing stage	16.7	0.73	138	4,267	2,946	2,460	1,643
			0.12	23	69			
FV1260	10% ear emergence	16.3	0.68	97	4,192	2,757	2,351	1,531
			0.11	16	66			
Full harvest year, 2nd growth								
FV1340	leafy regrowth 5 w.	20.5	0.62	106	4,266	2,572	2,196	1,386
			0.13	22	60			
Full harvest year, 3rd growth								
FV1390	leafy regrowth 6 w.	18.2	0.63	111	4,253	2,611	2,216	1,414
			0.11	20	61			
Legumes, lucerne								
First growth								
FV2120	50% bud	17.6	0.63	131	4,431	2,657	2,252	1,419
			0.11	23	60			
FV2140	flowerinig	21.7	0.55	113	4,434	2,374	2,034	1,227
			0.12	24	54			
2nd G.(1st cut:budd.)								
FV2150	stemmy regrowth 5 w.	19.3	0.66	154	4,509	2,800	2,338	1,488
			0.13	30	62			
3rd growth								
FV2220	stemmy regrowth 5 w.	21.0	0.67	168	4,487	2,834	2,339	1,513
			0.14	35	63			
4th growth								
FV2250	stemmy regrowth 5 w.	19.1	0.68	178	4,370	2,854	2,316	1,540
			0.13	34	65			
Legumes, red clover								
First growth								
FV2320	50% bud	14.3	0.72	112	4,303	2,948	2,466	1,617
			0.10	16	68			
FV2340	flowerinig	18.0	0.63	96	4,322	2,637	2,250	1,409
			0.11	17	61			
2nd G.(1st cut:budd.)								
FV2370	stemmy regrowth 6 w.	16.4	0.71	132	4,324	2,916	2,416	1,598
			0.12	22	67			
3rd growth								
FV2400	stemmy regrowth 6 w.	14.2	0.74	145	4,198	3,010	2,450	1,671
			0.11	21	72			

Bold print: per kg DM Normal characters: per kg as fed or digestibility coefficent %

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
875	210		233	537	248				3.4	3.8	1.6
74	73										
878	159		256	560	284				2.3	2.9	1.6
81	68										
892	166		290	614	315				3.0	5.2	1.8
65	71										
886	174		273	600	297				3.0	6.2	1.8
66	71										
888	193		299	488	315				2.7	16.1	1.5
64	75										
898	168		333	525	344				2.3	16.1	1.5
58	74										
894	222		286	487	311				2.7	14.6	2.0
67	77										
882	241		261	468	287				2.7	18.5	2.0
68	77										
850	259		207	442	259				2.7	18.0	2.0
70	76										
883	180		232	447	280				2.7	12.7	3.0
73	69										
897	154		289	491	326				2.3	12.2	3.0
66	69										
878	205		219	452	279				2.7	13.7	3.5
72	72										
842	226		166	426	256				3.0	12.2	3.5
77	71										

Code INRA	Silages	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Natural grassland, lowlands (Normandy)								
Wilted, fine chop								
FE0490	First growth	33.5	0.62	66	4,509	2,768	2,268	1.406
	5/25 10%ear emergence		0.21	22	61			
FE0500	First growth	33.5	0.56	55	4,533	2,535	2,114	1.266
	6/10 50%ear emergence		0.19	18	56			
FE0530	Reg. aft. earl. graz.	33.5	0.59	56	4,535	2,635	2,201	1,322
	stemmy regrowth 7 w.		0.20	19	58			
FE0560	2nd growth	33.5	0.62	78	4,529	2,780	2,252	1,399
	leafy regrowth 7 w.		0.21	26	61			
Wilted >50 % DM, baled or wrapped								
FE0580	First growth	55.0	0.60	80	4,437	2,674	2,205	1,353
	5/25 10%ear emergence		0.33	44	60			
FE0590	First growth	55.0	0.53	64	4,427	2,410	2,019	1,200
	6/10 50%ear emergence		0.29	35	54			
FE0600	First growth	55.0	0.47	53	4,400	2,138	1,809	1,047
	6/25 flowering		0.26	29	49			
FE0660	2nd growth	55.0	0.60	98	4,470	2,694	2,193	1,351
	leafy regrowth 7 w.		0.33	54	60			
Natural grassland, Mid Mountains (Auvergne)								
Wilted, fine chop								
FE0920	First growth	33.5	0.63	95	4,493	2,807	2,279	1,428
	6/10 10%ear emergence		0.21	32	62			
FE0930	First growth	33.5	0.56	71	4,483	2,507	2,083	1,255
	6/25 50%ear emergence		0.64	24	56			
FE0940	2nd growth	33.5	0.22	136	4,535	2,883	2,255	1,447
	leafy regrowth 6 w.			46	64			
Wilted >50 % DM, baled or wrapped								
FE0960	First growth	55.0	0.61	72	4,403	2,696	2,200	1,363
	6/10 10%ear emergence		0.33	39	61			
FE0970	First growth	55.0	0.53	51	4,359	2,373	1,982	1,183
	6/25 50%ear emergence		0.29	28	54			
FE0980	First growth	55.0	0.45	40	4,304	2,050	1,729	1,003
	7/10 flowering		0.25	22	48			
FE0990	2nd growth	55.0	0.62	107	4,483	2,789	2,189	1,388
	leafy regrowth 6 w.		0.34	59	62			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
896	141	4.80	285	549	313				3.2	6.3	2.2
66	66										
909	120	3.70	324	582	345				3.1	5.7	2.2
60	65										
909	121	3.80	328	585	349				3.1	6.3	2.1
62	66										
893	160	5.80	285	549	313				3.2	8.0	2.0
66	70										
912	134	4.40	301	562	326				3.2	6.3	2.2
65	66										
919	112	3.30	332	588	352				3.1	5.7	2.2
59	64										
919	96	2.50	349	603	366				3.1	5.2	2.4
52	61										
910	155	5.50	301	562	326				3.2	8.0	2.0
65	70										
906	154	5.50	276	541	306				2.4	5.3	1.9
67	68										
916	122	3.80	315	574	338				1.8	4.9	1.9
60	65										
895	206	8.10	245	514	280				2.4	8.2	1.9
68	73										
917	149	5.20	293	556	320				2.4	5.3	1.9
66	69										
922	114	3.40	325	583	346				1.8	4.9	1.9
59	64										
917	96	2.50	340	595	358				1.5	3.6	1.9
51	59										
911	205	8.10	268	534	299				2.4	8.2	1.9
67	75										

Code INRA	**Silages**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Grasses, Ita. ryegrass none alternative								
Wilted, fine chop								
FE1580	First growth	33.5	0.63	47	4,298	2,685	2,229	1,415
	10% ear emergence		0.21	16	62			
FE1600	First growth	33.5	0.57	36	4,309	2,457	2,079	1,273
	end of heading		0.19	12	57			
FE1630	2nd growth	33.5	0.55	61	4,347	2,431	2,010	1,232
	stemmy regrowth 7 w.		0.18	20	56			
Wilted >50 % DM, baled or wrapped								
FE1650	First growth	55.0	0.61	55	4,235	2,593	2,171	1,361
	10% ear emergence		0.33	30	61			
FE1670	First growth	55.0	0.54	39	4,218	2,337	1,993	1,207
	end of heading		0.30	21	55			
FE1680	First growth	55.0	0.50	32	4,204	2,207	1,893	1,133
	early flowering		0.28	17	52			
FE1710	2nd growth	55.0	0.52	74	4,278	2,329	1,936	1,176
	stemmy regrowth 7 w.		0.29	40	54			
Grasses, perennial ryegrass								
Wilted, fine chop								
FE2590	Late flower 1st grow.	33.5	0.62	51	4,293	2,682	2,249	1,392
	10% ear emergence		0.21	17	62			
FE2610	Late flower 1st grow.	33.5	0.56	35	4,283	2,442	2,084	1,255
	end of heading		0.19	12	57			
FE2630	2nd growth	33.5	0.58	61	4,328	2,562	2,115	1,314
	stemmy regrowth 7 w.		0.20	20	59			
Wilted >50 % DM, baled or wrapped								
FE2740	Late flower 1st grow.	55.0	0.61	59	4,233	2,592	2,204	1,375
	10% ear emergence		0.34	33	61			
FE2760	Late flower 1st grow.	55.0	0.54	38	4,199	2,326	2,014	1,222
	end of heading		0.30	21	55			
FE2770	Late flower 1st grow.	55.0	0.52	37	4,212	2,252	1,953	1,175
	early flowering		0.29	20	53			
FE2790	2nd growth	55.0	0.57	74	4,270	2,490	2,078	1,292
	stemmy regrowth 7 w.		0.32	41	58			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
890	117	3.60	254	520	283				2.6	4.6	1.3
67	57										
901	95	2.50	297	571	327				2.3	4.6	1.3
61	54										
895	132	4.30	301	575	331				2.6	4.6	1.3
60	66										
908	108	3.10	275	545	305				2.6	4.6	1.3
66	57										
914	85	1.90	310	586	340				2.3	4.6	1.3
60	51										
915	76	1.50	317	594	347				2.3	4.6	1.3
57	46										
911	125	4.00	314	590	344				2.6	4.6	1.3
59	65										
889	117	3.60	304	586	328				2.8	5.8	1.4
67	62										
897	91	2.20	327	612	353				2.6	5.8	1.4
61	56										
890	134	4.40	288	568	312				2.8	5.8	1.6
64	65										
908	108	3.10	316	599	341				2.8	5.8	1.4
66	61										
912	81	1.70	335	620	361				2.6	5.8	1.4
60	52										
916	79	1.60	344	631	371				2.3	5.8	1.4
58	52										
908	127	4.10	303	585	328				2.8	5.8	1.6
63	65										

Code INRA	**Silages**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Grasses, cocksfoot								
Wilted, fine chop								
FE3980	First growth	33.5	0.61	79	4,292	2,729	2,198	1,378
	10% ear emergence		0.21	26	64			
FE40000	First growth	33.5	0.54	61	4,319	2,462	2,040	1,222
	end of heading		0.18	20	57			
FE4040	2nd growth	33.5	0.53	75	4,340	2,427	1,976	1,192
	leafy regrowth 7 w.		0.18	25	56			
Wilted >50 % DM, baled or wrapped								
FE4070	First growth	55.0	0.60	100	4,288	2,668	2,161	1,343
	10% ear emergence		0.33	55	62			
FE4090	First growth	55.0	0.52	73	4,261	2,361	1,964	1,170
	end of heading		0.29	40	55			
FE4100	First growth	55.0	0.49	67	4,266	2,239	1,877	1,099
	early flowering		0.27	37	52			
FE4140	2nd growth	55.0	0.52	92	4,295	2,380	1,947	1,169
	leafy regrowth 7 w.		0.29	51	55			
Whole crop cereals, whole plant maize								
Normal conditions of growth								
FE4710	Fine chop, no additi.	30.0	0.87	29	4,452	2,983	2,706	1,956
	Dough, 30% DM		0.26	9	67			
FE4720	Fine chop, no additi.	35.0	0.87	29	4,452	2,983	2,735	1,957
	Flint, 35% DM		0.31	10	67			
Bad conditions of growth								
FE4770	Fine chop, no additi.	32.0	0.80	33	4,411	2,797	2,517	1,807
	Summer drought (low ear content)		0.26	11	63			

Bold print: per kg DM Normal characters: per kg as fed or digestibility coefficent %

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
871	163	5.90	270	574	293				2.3	2.7	1.4
68	69										
890	129	4.20	325	630	351				2.3	2.7	1.4
61	67										
886	151	5.30	314	618	340				2.6	5.2	1.4
60	71										
898	158	5.70	289	593	313				2.3	2.7	1.4
67	70										
908	122	3.80	333	638	360				2.3	2.7	1.4
60	66										
914	113	3.40	350	655	378				2.3	2.7	1.4
57	66										
906	145	5.00	324	629	351				2.6	5.2	1.4
60	70										
954	69		205	444	226				1.8	2.0	1.2
72	51										
954	69		201	441	221				1.8	2.0	1.2
72	51										
943	77		203	465	223				1.8	2.0	1.2
68	51										

Code INRA	Hays	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Natural grassland, lowlands (Normandy)								
Barn-dried								
FF0010	First growth	85.0	0.69	95	4,437	2,821	2,399	1,542
	05 / 10 leafy		0.58	81	64			
FF0020	First growth	85.0	0.62	68	4,418	2,567	2,221	1,386
	5/25 10%ear emergence		0.52	58	58			
FF0030	First growth	85.0	0.55	52	4,420	2,326	2,042	1,231
	6/10 50%ear emergence		0.46	44	53			
FF0050	2nd growth	85.0	0.62	83	4,445	2,583	2,220	1,390
	leafy regrowth 7 w.		0.52	71	58			
Field-cured, no rain								
FF0060	First growth	85.0	0.62	68	4,418	2,567	2,221	1,386
	5/25 10%ear emergence		0.52	58	58			
FF0070	First growth	85.0	0.55	52	4,434	2,334	2,049	1,235
	6/10 50%ear emergence		0.47	44	53			
FF0080	First growth	85.0	0.48	40	4,410	2,080	1,842	1,082
	6/25 flowering		0.41	34	47			
FF0130	2nd growth	85.0	0.62	83	4,445	2,583	2,220	1,390
	leafy regrowth 7 w.		0.52	71	58			
FF0150	3rd growth	85.0	0.64	99	4,387	2,645	2,247	1,430
	leafy regrowth 8 w.		0.54	84	60			
Field-cured, rain<10d								
FF0160	First growth	85.0	0.58	65	4,405	2,463	2,144	1,315
	5/25 10%ear emergence		0.50	55	56			
FF0170	First growth	85.0	0.53	48	4,420	2,278	2,010	1,196
	6/10 50%ear emergence		0.45	41	52			
FF0180	First growth	85.0	0.46	37	4,397	2,026	1,803	1,045
	6/25 flowering		0.39	31	46			
FF0230	2nd growth	85.0	0.59	80	4,427	2,476	2,140	1,317
	leafy regrowth 7 w.		0.50	68	56			
Natural grassland, Mediterranean lowlands (CRAU)								
Field-cured, no rain								
FF0360	First growth	85.0	0.60	57	4,369	2,491	2,160	1,349
	05/10: early 1st cut		0.51	49	57			
FF0370	First growth	85.0	0.47	47	4,380	2,018	1,774	1,053
	05/25: late 1st cut		0.40	40	46			
FF0380	2nd growth	85.0	0.57	65	4,446	2,389	2,060	1,289
	07/25: 2nd cut		0.49	55	54			
FF0390	3rd growth	85.0	0.62	72	4,406	2,560	2,195	1,395
	08/25: 3rd cut		0.53	62	58			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
900 68	165 68	6.90	269	566	300				3.3	4.9	3.0
910 62	127 63	4.60	295	591	321				3.2	4.6	2.0
919 57	104 59	3.20	333	628	353				3.1	4.2	2.0
908 62	148 66	5.80	295	591	321				3.2	5.6	2.2
910 62	127 63	4.60	295	591	321				3.2	4.6	2.0
922 57	104 59	3.20	333	628	353				3.1	4.2	2.0
923 51	88 54	2.20	353	648	369				3.1	3.9	2.2
908 62	148 66	5.80	295	591	321				3.2	5.6	2.2
887 65	170 68	7.20	272	569	302				3.3	4.6	3.1
909 60	122 62	4.30	317	613	340				3.2	4.6	2.0
921 56	99 57	2.90	351	646	368				3.1	4.2	2.0
922 50	83 52	1.90	370	664	384				3.1	3.9	2.2
906 60	143 65	5.50	317	613	340				3.2	5.6	2.2
905 61	112 60	3.70	281	578	310				3.0	10.5	3.0
913 50	97 57	2.80	328	623	349				3.0	10.0	2.5
918 58	122 62	4.30	269	566	300				3.0	11.0	2.5
905 62	133 64	4.90	258	556	291				4.0	13.0	2.5

Code INRA	**Hays**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Natural grassland, Mid Mountains (Auvergne)								
Barn-dried								
FF0420	First growth	85.0	0.71	91	4,470	2,891	2,454	1,597
	05 / 20 leafy		0.60	77	65			
FF0430	First growth	85.0	0.64	79	4,472	2,647	2,275	1,435
	6/10 10%ear emergence		0.54	67	59			
FF0440	First growth	85.0	0.55	53	4,442	2,338	2,048	1,241
	6/25 50%ear emergence		0.47	45	53			
FF0460	2nd growth	85.0	0.66	120	4,540	2,737	2,296	1,485
	leafy regrowth 6 w.		0.56	102	60			
Field-cured, no rain								
FF0490	First growth	85.0	0.64	79	4,486	2,655	2,283	1,440
	6/10 10%ear emergence		0.54	67	59			
FF0500	First growth	85.0	0.55	53	4,465	2,350	2,058	1,248
	6/25 50%ear emergence		0.47	45	53			
FF0510	First growth	85.0	0.47	40	4,392	2,023	1,788	1,053
	07/10: flowering		0.40	34	46			
FF0520	2nd growth	85.0	0.66	120	4,545	2,740	2,298	1,487
	leafy regrowth 6 w.		0.56	102	60			
Field-cured, rain<10d								
FF0550	First growth	85.0	0.61	75	4,472	2,550	2,205	1,367
	6/10 10%ear emergence		0.52	64	57			
FF0560	First growth	85.0	0.54	50	4,451	2,294	2,020	1,208
	6/25 50%ear emergence		0.46	42	52			
FF0570	First growth	85.0	0.45	37	4,379	1,969	1,749	1,016
	07/10: flowering		0.38	31	45			
FF0580	2nd growth	85.0	0.61	116	4,527	2,581	2,178	1,381
	leafy regrowth 6 w.		0.52	99	57			
Grasses, Ita. ryegrass none alternative								
Barn-dried								
FF1060	First growth	85.0	0.66	54	4,279	2,617	2,289	1,494
	10% ear emerg. -1 we.		0.56	46	61			
FF1080	First growth	85.0	0.59	38	4,250	2,376	2,106	1,333
	50% ear emergence		0.50	32	56			
FF1120	2nd growth	85.0	0.56	61	4,312	2,269	1,999	1,249
	stemmy regrowth 7 w.		0.47	52	53			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
909	159	6.50	250	548	284				2.4	4.2	2.5
69	67										
916	142	5.50	285	582	313				2.2	3.9	1.7
64	65										
923	106	3.30	324	619	345				1.8	3.7	1.7
57	59										
909	200	9.00	255	553	288				2.2	5.8	1.7
65	71										
919	142	5.50	285	582	313				2.2	3.9	1.7
64	65										
928	106	3.30	324	619	345				1.8	3.7	1.7
57	59										
919	88	2.20	342	637	360				1.6	2.9	1.7
50	54										
910	200	9.00	255	553	288				2.2	5.8	1.7
65	71										
918	137	5.20	308	604	332				2.2	3.9	1.7
61	65										
927	101	3.00	344	639	362				1.8	3.7	1.7
56	58										
918	83	1.90	360	654	375				1.6	2.9	1.7
49	52										
908	195	8.70	280	577	309				2.2	5.8	1.7
61	70										
906	107	3.40	256	567	291				2.4	3.5	2.0
66	59										
908	84	2.00	288	594	318				2.2	3.5	1.4
60	53										
909	117	4.00	310	622	340				2.4	3.5	1.4
57	61										

Code INRA	**Hays**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Grasses, Ita. ryegrass none alternative								
Field-cured, no rain								
FF1140	First growth	85.0	0.59	38	4,250	2,376	2,106	1,333
	50% ear emergence		0.50	32	56			
FF1170	First growth	85.0	0.47	18	4,248	1,957	1,762	1,065
	flowerinig		0.40	16	46			
FF1190	2nd growth	85.0	0.56	61	4,316	2,272	2,001	1,251
	stemmy regrowth 7 w.		0.47	52	53			
FF1220	3rd growth	85.0	0.64	78	4,322	2,558	2,208	1,451
	leafy regrowth 7 w.		0.55	66	59			
Field-cured, rain<10d								
FF1250	First growth	85.0	0.56	34	4,232	2,274	2,027	1,261
	50% ear emergence		0.48	29	54			
FF1280	First growth	85.0	0.46	15	4,235	1,905	1,723	1,028
	flowerinig		0.39	13	45			
FF1300	2nd growth	85.0	0.54	57	4,298	2,215	1,962	1,209
	stemmy regrowth 7 w.		0.46	49	52			
Grasses, perennial ryegrass								
Barn-dried								
FF1520	Late flower 1st grow.	85.0	0.65	58	4,271	2,612	2,300	1,469
	10% ear emerg. -1 we.		0.56	49	61			
FF1540	Late flower 1st grow.	85.0	0.60	37	4,253	2,424	2,164	1,349
	50% ear emergence		0.51	31	57			
FF1570	2nd growth	85.0	0.59	62	4,302	2,405	2,112	1,338
	stemmy regrowth 7 w.		0.51	53	56			
Field-cured, no rain								
FF1640	Late flower 1st grow.	85.0	0.60	37	4,253	2,424	2,164	1,349
	50% ear emergence		0.51	31	57			
FF1660	Late flower 1st grow.	85.0	0.53	27	4,269	2,200	1,980	1,204
	early flowerinig		0.45	23	52			
FF1680	2nd growth	85.0	0.59	62	4,297	2,403	2,110	1,337
	stemmy regrowth 7 w.		0.51	53	56			
FF1710	2nd growth	85.0	0.67	95	4,345	2,667	2,294	1,504
	leafy regrowth 7 w.		0.57	81	61			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
908	84	2.00	288	594	318				2.2	3.5	1.4
60	53										
918	57	0.40	327	644	358				1.9	3.5	1.2
50	38										
910	117	4.00	310	622	340				2.4	3.5	1.4
57	61										
902	141	5.40	243	535	272				2.7	4.3	1.4
64	65										
906	79	1.70	311	623	341				2.2	3.5	1.4
58	51										
917	52	0.10	346	669	377				1.9	3.5	1.2
49	34										
908	112	3.70	331	649	362				2.4	3.5	1.4
56	60										
902	113	3.70	302	619	326				2.7	4.3	1.5
66	61										
909	83	1.90	325	647	350				2.4	4.3	1.6
61	52										
906	119	4.10	297	613	321				2.7	4.3	1.8
60	62										
909	83	1.90	325	647	350				2.4	4.3	1.6
61	52										
918	69	1.10	347	674	374				2.2	4.3	1.6
56	46										
905	119	4.10	297	613	321				2.7	4.3	1.8
60	62										
898	165	6.90	264	573	286				2.9	4.7	1.8
66	68										

Code INRA	Hays	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Grasses, perennial ryegrass								
Field-cured, rain<10d								
FF1840	Late flower 1st grow.	85.0	0.57	33	4,235	2,322	2,083	1,277
	50% ear emergence		0.48	28	55			
FF1860	Late flower 1st grow.	85.0	0.52	23	4,251	2,145	1,940	1,164
	early flowerinig		0.44	20	50			
FF1880	2nd growth	85.0	0.56	59	4,279	2,299	2,030	1,265
	stemmy regrowth 7 w.		0.48	50	54			
FF1910	2nd growth	85.0	0.63	92	4,323	2,559	2,214	1,427
	leafy regrowth 7 w.		0.54	78	59			
Grasses, tall fescue								
Barn-dried								
FF2180	First growth	85.0	0.57	74	4,248	2,399	2,059	1,289
	10% ear emerg. -1 we.		0.49	63	56			
FF2190	First growth	85.0	0.51	53	4,234	2,182	1,906	1,150
	50% ear emergence		0.43	45	52			
FF2210	2nd growth	85.0	0.54	69	4,245	2,281	1,971	1,211
	leafy regrowth 7 w.		0.46	59	54			
Field-cured, no rain								
FF2230	First growth	85.0	0.51	56	4,216	2,173	1,898	1,145
	50% ear emergence		0.43	48	52			
FF2260	First growth	85.0	0.42	46	4,205	1,845	1,629	946
	flowerinig		0.36	39	44			
FF2270	Reg. aft. earl. graz.	85.0	0.54	75	4,133	2,266	1,953	1,204
	stemmy regrowth 5 w.		0.45	63	55			
FF2280	2nd growth	85.0	0.53	72	4,218	2,266	1,959	1,202
	leafy regrowth 7 w.		0.45	61	54			
Field-cured, rain<10d								
FF2310	First growth	85.0	0.49	52	4,198	2,118	1,860	1,106
	50% ear emergence		0.42	45	50			
FF2340	First growth	85.0	0.40	42	4,187	1,792	1,590	911
	flowerinig		0.34	36	43			
FF2350	Reg. aft. earl. graz.	85.0	0.50	71	4,101	2,159	1,872	1,133
	stemmy regrowth 5 w.		0.43	60	53			
FF2360	2nd growth	85.0	0.52	69	4,196	2,208	1,919	1,161
	leafy regrowth 7 w.		0.44	58	53			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
907	78	1.60	345	672	371				2.4	4.3	1.6
59	50										
916	64	0.80	365	696	393				2.2	4.3	1.6
54	43										
903	114	3.80	319	640	344				2.7	4.3	1.8
58	61										
895	160	6.60	288	602	312				2.9	4.7	1.8
64	67										
888	135	5.10	273	584	296				2.7	2.7	2.5
61	64										
896	106	3.30	316	643	346				2.4	2.7	2.0
56	59										
890	128	4.60	296	619	326				2.9	3.5	1.7
58	63										
892	106	4.60	316	643	346				2.4	2.7	2.0
56	62										
895	92	2.50	348	682	379				2.2	2.7	1.5
47	59										
864	131	4.80	288	609	318				2.9	3.5	1.5
59	67										
884	128	4.60	296	619	326				2.9	3.5	1.7
58	66										
890	101	3.00	336	668	367				2.4	2.7	2.0
54	61										
893	87	2.20	366	704	398				2.2	2.7	1.0
46	57										
859	126	4.50	311	637	341				2.9	3.5	2.0
57	66										
881	123	4.30	317	644	347				2.9	3.5	1.7
57	66										

Code INRA	**Hays**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Grasses, cocksfoot								
Barn-dried								
FF2460	First growth	85.0	0.65	114	4,369	2,715	2,295	1,467
	10% ear emerg. -1 we.		0.55	97	62			
FF2470	First growth	85.0	0.59	80	4,303	2,500	2,159	1,336
	50% ear emergence		0.50	68	58			
FF2490	2nd growth	85.0	0.54	80	4,323	2,322	2,011	1,223
	leafy regrowth 7 w.		0.46	68	54			
Field-cured, no rain								
FF2520	2nd growth	85.0	0.59	80	4,289	2,492	2,152	1,331
	leafy regrowth 7 w.		0.50	68	58			
FF2550	First growth	85.0	0.45	46	4,293	1,978	1,748	1,019
	flowerinig		0.38	40	46			
FF2570	Reg. aft. earl. graz.	85.0	0.38	40	4,282	1,691	1,499	859
	stemmy regrowth 8 w.		0.32	34	40			
FF2590	2nd growth	85.0	0.54	80	4,314	2,318	2,006	1,220
	leafy regrowth 7 w.		0.46	68	54			
Field-cured, rain<10d								
FF2660	First growth	85.0	0.56	76	4,272	2,389	2,074	1,262
	50% ear emergence		0.48	65	56			
FF2690	First growth	85.0	0.44	43	4,275	1,923	1,708	982
	flowerinig		0.37	36	45			
FF2710	Reg. aft. earl. graz.	85.0	0.37	36	4,268	1,640	1,460	825
	stemmy regrowth 8 w.		0.31	31	38			
FF2730	2nd growth	85.0	0.51	77	4,296	2,214	1,927	1,153
	leafy regrowth 7 w.		0.44	65	52			
Legumes, lucerne								
Barn-dried								
FF3220	First growth	85.0	0.58	114	4,348	2,514	2,128	1,308
	10% bud		0.49	97	58			
FF3240	First growth	85.0	0.53	104	4,351	2,330	1,992	1,194
	early flowerinig		0.45	88	54			
FF3270	2nd G.(1st cut:budd.)	85.0	0.55	111	4,387	2,396	2,041	1,230
	stemmy regrowth 7 w.		0.46	95	55			
Field-cured, no rain								
FF3330	First growth	85.0	0.54	106	4,402	2,357	2,018	1,204
	50% bud		0.45	90	54			
FF3350	First growth	85.0	0.49	98	4,419	2,178	1,879	1,095
	flowerinig		0.41	83	49			
FF3370	2nd G.(1st cut:budd.)	85.0	0.54	108	4,434	2,374	2,035	1,209
	stemmy regrowth 7 w.		0.46	92	54			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
896	185	8.10	275	593	304				2.4	2.7	3.0
67	73										
899	138	5.20	307	647	332				2.2	2.3	1.5
62	68										
903	139	5.20	323	665	349				2.4	3.9	1.5
58	68										
896	138	5.20	307	647	332				2.2	2.3	1.5
62	68										
914	93	2.50	357	704	385				1.9	1.9	1.5
50	59										
915	84	2.50	356	703	384				2.4	3.5	1.7
43	56										
901	139	5.30	323	665	349				2.4	3.9	1.5
58	68										
894	133	4.90	328	671	355				2.2	2.3	1.5
60	67										
912	88	2.20	374	723	403				1.9	1.9	1.5
49	57										
914	79	1.70	373	722	402				2.4	3.5	1.7
42	54										
899	134	5.00	343	688	371				2.4	3.9	1.5
56	67										
891	185	8.10	311	520	326				2.4	12.5	2.5
62	73										
897	171	7.20	338	539	343				2.4	12.5	2.5
58	72										
901	181	7.80	338	539	343				2.2	11.0	2.0
59	72										
907	174	4.70	351	548	352				2.4	12.5	2.5
58	72										
915	163	6.70	374	564	367				2.2	12.5	2.5
53	71										
913	177	7.60	361	555	359				2.2	11.0	2.0
58	72										

Code INRA	**Hays**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Legumes, red clover								
Barn-dried								
FF3520	First growth	85.0	**0.62**	**111**	**4,290**	**2,618**	**2,191**	**1,398**
	10% bud		0.53	94	61			
FF3540	First growth	85.0	**0.56**	**89**	**4,306**	**2,398**	**2,049**	**1,253**
	early flowerinig		0.47	75	56			
Field-cured								
FF3620	First growth	85.0	**0.53**	**101**	**4,294**	**2,300**	**1,946**	**1,199**
	50% bud		0.45	86	54			
FF3640	First growth	85.0	**0.49**	**82**	**4,313**	**2,171**	**1,874**	**1,110**
	flowerinig		0.42	70	50			
FF3660	2nd G.(1st cut:budd.)	85.0	**0.53**	**110**	**4,351**	**2,284**	**1,928**	**1,185**
	stemmy regrowth 7 w.		0.45	93	52			

Bold print: per kg DM Normal characters: per kg as fed or digestibility coefficent %

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
880	180	7.80	245	485	299				2.7	10.3	2.0
66	72										
895	150	6.00	301	524	337				2.2	9.9	2.0
60	69										
886	167	7.00	280	509	323				2.4	9.9	2.0
58	71										
900	141	5.40	337	549	361				2.2	9.5	2.0
54	68										
894	179	7.70	286	514	327				2.4	10.3	2.5
57	72										

Code INRA	**Straws, stovers, husks**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
FP0020	Wheat, Alone (a)	88.0	0.29	0	4,340	1,393	1,259	653
			0.26	0	32			
FP0040	Wheat, Ammonia-treated 5% DM	88.0	0.37	40	4,380	1,738	1,539	833
			0.33	35	40			
FP0060	Barley Straw, Alone (a)	88.0	0.32	0	4,300	1,503	1,356	720
			0.28	0	35			
FP0080	Barley Straw, Ammonia-treated 5% DM	88.0	0.39	40	4,300	1,829	1,619	878
			0.35	35	43			
FP0090	Oat straw, Alone (a)	88.0	0.35	0	4,240	1,642	1,485	788
			0.31	0	39			
FP0140	Grass seed straw	88.0	0.36	30	4,340	1,681	1,490	810
			0.32	27	39			
FP0160	Pea straw, Alone (a)	88.0	0.36	20	4,130	1,678	1,500	810
			0.31	17	41			

Bold print: per kg DM Normal characters: per kg as fed or digestibility coefficent %

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
920	35		420	798	504				1.0	2.0	1.0
35	0										
915	100		419	766	504				1.0	3.5	1.0
43	57										
920	38		420	798	504				1.0	3.5	1.0
38	0										
920	100		420	766	504				1.0	3.5	1.5
46	57										
910	32		420	760	470				1.0	3.5	1.0
42	0										
926	84		400	760	480				1.0	3.0	1.0
42	52										
901	66		413						1.0	5.0	1.0
44	43										

Code INRA	**Roots, tubers**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
FR0010	Fodder beet (a)	13.0	1.13	52	4,110	3,452	3,224	2,543
			0.15	7	84			
FR0030	Sugar-beet (a)	23.2	1.13	44	4,020	3,417	3,239	2,543
			0.26	10	85			
FR0040	Carrots (a)	12.5	1.10	49	4,030	3,506	3,257	2,475
			0.14	6	87			

Bold print: per kg DM Normal characters: per kg as fed or digestibility coefficent %

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
915	104		70						1.5	2.5	1.3
87	66										
968	84		58						1.5	3.0	1.3
88	70										
910	105		100						3.0	4.5	1.9
88	62										

Code INRA	**Ingredients**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Dehydrated forages (a)								
First growth (a)								
CD0020	Lucerne <16% CP	91.4	0.57	86	4,302	2,318	1,991	1,283
			0.52	79	54			
CD0030	Lucerne 17-18% CP	90.6	0.60	104	4,301	2,435	2,067	1,350
			0.54	94	57			
CD0040	Lucerne 18-19% CP	90.6	0.62	110	4,299	2,515	2,123	1,395
			0.56	100	58			
CD0050	Lucerne 22-25% CP	89.8	0.70	146	4,279	2,840	2,326	1,579
			0.63	131	66			
CD0060	Corn, milk stage	91.0	0.77	32	4,417	2,739	2,446	1,734
			0.70	29	62			
CD0070	Corn, glaze stage	91.0	0.92	29	4,424	3,008	2,755	2,069
			0.84	26	68			
CD0080	Ita. Ryegrass 1st cut	91.0	0.73	53	4,190	2,757	2,404	1,647
			0.66	48	66			
CD0090	Ita. Ryegrass 2nd cut	91.0	0.71	92	4,240	2,650	2,247	1,606
			0.65	84	63			
Cereals								
CC0010	Barley	86.7	1.14	82	4,390	3,480	3,247	2,565
			0.99	71	79			
CC0020	Oats	88.1	0.99	78	4,656	3,151	2,871	2,288
			0.87	69	68			
CC0030	Oats, decorticated	85.6	1.14	92	4,484	3,518	3,268	2,588
			0.98	79	78			
CC0040	Wheat, durum	87.6	1.21	116	4,425	3,744	3,456	2,723
			1.06	102	85			
CC0050	Wheat, high moisture	86.8	1.23	85	4,351	3,675	3,473	2,765
			1.07	74	84			
CC0060	Maize	86.4	1.30	66	4,463	3,803	3,647	2,925
			1.12	57	85			
CC0070	Rice, paddy	87.4	1.33	65	4,299	3,751	3,672	2,993
			1.16	57	87			
CC0080	Rye	87.3	1.20	63	4,294	3,655	3,421	2,706
			1.05	55	85			
CC0090	Sorghum	86.5	1.24	77	4,502	3,637	3,470	2,783
			1.07	67	81			
CC0100	Triticale	87.3	1.21	77	4,311	3,603	3,412	2,723
			1.06	67	84			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
892	151	6.40	320	503	363	91	24		2.6	20.4	1.6
59	67										
885	175	8.00	295	474	338	86	27		2.6	21.8	1.7
61	70										
883	184	8.50	283	467	326	83	28		2.7	22.3	1.7
62	71										
871	233	11.70	211	379	255	69	34		2.7	25.2	1.9
70	74										
950	76		223	496	247	27	25	170	1.8	2.3	1.5
67	50										
954	72		195	450	215	23	30	300	1.8	2.3	1.5
68	47										
899	105		238	508	269		25		2.7	4.3	1.0
69	59										
889	161		263	553	292		25		3.0	4.8	2.0
67	68										
974	116	4.40	52	216	63	11	21	602	4.0	0.8	1.3
83	81										
970	111	4.70	138	372	169	28	54	411	3.6	1.2	1.1
70	81										
975	124	5.10	47	136	54	20	29	615	3.3	1.0	1.0
82	81										
978	165	4.30	31	164	43	13	21	633	3.9	0.9	1.2
88	81										
982	121	3.60	26	143	36	11	17	698	3.7	0.8	1.1
88	81										
986	94	2.80	25	120	30	6	43	742	3.0	0.5	1.2
89	81										
988	92	3.40	5	10	7	0	13	868	2.3	0.1	1.6
91	82										
979	103	4.00	22	161	36	10	14	616	3.4	1.2	1.2
89	70										
983	109	2.50	27	108	43	12	34	741	3.2	0.3	1.4
84	81										
978	110	4.50	27	146	37	12	15	686	4.0	0.8	1.1
87	81										

Code INRA	Ingredients	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Cereal by-product								
CS0010	Wheat middlings, durum	86.9	0.98	134	4,606	3,276	2,886	2,205
			0.85	116	71			
CS0020	Wheat bran, durum	86.6	0.89	129	4,585	3,053	2,656	2,203
			0.77	112	67			
CS0030	Wheat feed flour	88.2	1.24	109	4,515	3,737	3,498	2,781
			1.09	96	83			
CS0040	Wheat shorts	87.9	1.13	128	4,553	3684	3,293	2,543
			0.99	113	81			
CS0050	Wheat middlings	88.1	0.97	129	4,542	3,271	2,869	2,183
			0.85	114	72			
CS0060	Wheat bran	87.1	0.86	122	4,511	2,964	2,570	1,937
			0.75	106	66			
CS0090	Wheat gluten feed, starch	90.6	0.94	117	4,439	3,222	2,778	2,111
	25% as fed		0.85	106	73			
CS0100	Wheat gluten feed, starch	87.9	0.98	118	4,546	3,293	2,898	2,205
	28% as fed		0.86	104	72			
CS0110	Corn gluten feed	88.0	0.83	161	4,468	2,995	2,504	1,868
			0.73	142	67			
CS0120	Corn gluten meal	89.5	1.23	576	5,510	5,025	3,799	2,773
			1.10	513	91			
CS0140	Maize feed flour	87.3	1.21	61	4,632	3,706	3,427	2,690
			1.06	53	80			
CS0150	Maize starch	88.1	1.49	7	4,185	4,079	4,079	3,353
			1.31	6	97			
CS0170	Maize bran	87.8	0.87	69	4,506	2,849	2,559	1,958
			0.76	61	63			
CS0180	Maize germ meal, solvent-	87.4	0.90	217	4,658	3,447	2,778	2,025
	extractred		0.79	190	74			
CS0190	Maize germ meal, expeller	91.5	1.17	113	4,964	3,872	3,357	2,635
			1.07	103	78			
CS0200	Maize hominy feed	89.4	1.02	96	4,540	3,353	2,984	2,295
			0.91	86	74			
CS0220	Barley rootlets	89.3	0.76	166	4,415	3,782	2,320	2,719
			0.68	148	86			
CS0230	Rice, brokken	87.4	1.32	64	4,311	3,720	3,649	2,970
			1.15	56	86			
CS0240	Rice bran, defatted	90.2	0.85	88	4,220	2,785	2,451	1,907
			0.77	79	66			
CS0250	Rice bran, fat	90.1	1.07	90	5,133	3,592	3,143	2,408
			0.96	81	70			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
954	178	7.10	82	364	107	31	49	342	9.4	1.4	2.3
74	82										
944	169	6.60	117	499	151	43	51	230	11.2	1.6	3.1
69	83										
984	145	5.20	17	111	25	5	27	676	4.1	1.0	1.8
81	82										
962	170	6.70	56	261	74	22	40	430	8.1	1.3	2.6
83	82										
951	175	7.00	80	356	104	30	40	314	9.9	1.5	4.0
75	80										
942	170	6.70	105	455	136	39	40	227	11.4	1.6	4.8
68	78										
918	163	5.50	62	312	90	30	44	274	8.2	1.3	3.2
75	78										
953	164	5.60	69	324	95	31	32	317	8.5	1.8	2.6
75	78										
930	219	6.60	85	384	100	12	31	205	10.1	1.8	3.9
70	80										
979	677	12.00	12	26	8	2	28	192	5.4	0.8	0.4
95	90										
973	103	4.20	66	293	79	12	62	522	5.3	1.4	1.5
80	64										
997	9	0.00	2	0			5	950	0.0	0.2	0.0
100	89										
932	124	4.70	146	595	166	26	41	340	3.4	5.4	1.6
65	60										
964	295	7.90	101	425	119	17	29	155	7.2	0.5	3.1
76	80										
941	166	5.50	67	317	82	21	149	323	9.1	0.4	3.2
78	74										
948	149	5.20	62	298	75	14	68	403	8.6	1.6	2.9
77	70										
937	244	10.90	142	447	168	29	21	126	6.2	3.2	1.7
63	74										
990	88	3.20	12	59	15	6	14	882	2.5	0.5	1.7
90	80										
872	160	7.20	103	267	125	44	34	335	19.7	2.4	9.0
68	60										
910	153	6.80	86	228	99	36	182	304	17.9	0.9	7.3
72	64										

Code INRA	**Ingredients**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Other plant by-products								
CF0010	Cassava, starch 67% as fed	88.0	1.23	10	3,937	3,448	3,396	2,768
			1.08	9	88			
CF0010	Cassava, starch 72% as fed	87.3	1.28	9	4,073	3,533	3,512	2,880
			1.12	8	87			
CF0080	Soya bean hulls	89.4	0.69	40	4,355	2,494	2,170	1,560
			0.62	36	57			
CF0100	Carob pod meal	84.5	0.72	12	4,164	2,290	2,116	1,617
			0.61	10	55			
CF0130	Molasses, beet	75.7	1.18	11	3,685	3,496	3,195	2,655
			0.89	84	95			
CF0140	Molasses, cane	73.7	1.19	26	3,573	3,384	3,191	2,678
			0.88	19	95			
CF0170	Beet pulp, dehydrated	89.1	0.85	29	4,060	2,973	2,626	1,913
			0.76	26	73			
CF0180	Beet pulp, molassed, dehydrated	88.3	0.86	32	4,077	2,982	2,654	1,935
			0.76	28	73			
CF0200	Potato pulp, dehydrated	87.4	1.09	6	4,210	3,379	3,176	2,446
			0.95	5	80			
Fat								
CG0040	Oil	100.0	2.96		9,380	8,254	7,883	6,661
			2.96		88			
Legumes and oilseeds								
CN0010	Rape seed	92.2	1.43	154	6,836	5,947	4,438	3,218
			1.32	142	87			
CN0030	Horse bean, white flowers	86.1	1.10	243	4,475	3,835	3,252	2,475
			0.95	209	86			
CN0040	Horse bean, coloured flowers	86.5	1.11	229	4,479	3,837	3,307	2,520
			0.96	198	86			
CN0050	Linseed	90.3	1.30	188	6,402	5,075	4,035	2,925
			1.17	170	79			
CN0060	Lupin, white	88.6	1.05	290	5,060	4,000	3,296	2,363
			0.93	257	79			
CN0070	Lupin, blue	90.2	1.02	262	4,849	3,842	3,196	2,295
			0.92	236	79			
CN0080	Pea	86.4	1.11	186	4,366	3,629	3,223	2,498
			0.96	161	83			

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
938	31	1.30	50	97	69	24	7	762	1.1	2.6	1.2
91	45										
974	29	1.20	33	72	47	14	6	82	1.0	1.7	1.7
91	45										
947	134	7.90	382	631	452	24	25	0	1.5	5.5	2.5
60	50										
964	52	1.80	86	320	276	154	5	7	1.1	5.1	0.6
58	39										
871	154	2.10	0				2	0	0.3	1.4	0.6
91	85										
860	55	0.10	0				15	0	0.8	10.1	4.5
91	60										
923	91	7.20	194	454	231	21	10	0	1.0	14.8	2.0
76	45										
928	99	8.20	194	454	231	11	7	0	1.0	14.4	1.2
76	46										
964	53	0.70	182	297	206	58	4	432	1.5	6.2	1.6
82	17										
1000	0	0.00									
88	0										
657	207	12.90	89	190	134	59	455	0	7.2	5.1	
84	79										
959	311	20.00	87	160	106	8	13	433	5.5	1.7	
89	83										
961	894	19.20	91	161	107	9	15	442	5.3	1.6	
89	83										
952	250	9.90	102	245	148	62	362	0	6.8	4.2	
83	80										
961	385	18.70	128	214	154	10	95	0	4.3	3.8	
82	80										
962	340	17.10	165	247	197	17	59	0	4.1	3.6	
82	82										
995	239	17.40	60	139	69	3	12	516	4.6	1.3	
87	83										

Code INRA	**Ingredients**	Nutritional value						
		%	UF/kg	g/kg	Kcal/kg/%			
		DM	UFC	MADC	GE, Ed	DE	ME	NE
Legumes and oilseeds								
CN0090	Chickpea	89.0	1.11	174	4,708	3,710	3,257	2,498
			0.99	155	79			
CN0100	Soybean, whole seed, extruded	88.1	1.11	316	5,530	4,191	3,474	2,498
			0.98	278	76			
CN0120	Sunflower seed	93.0	1.30	128	6,849	4,851	4,007	2,295
			1.21	119	71			
Oilseed meals								
CX0010	Groundnut meal, detoxified,	89.6	1.02	461	4,617	4,118	3,232	2,295
	crude fibre <9% as fed		0.91	413	84			
CX0020	Groundnut meal, detoxified,	89.2	0.96	451	4,834	3,949	3,068	2,169
	crude fibre >9% as fed		0.86	402	82			
CX0040	Rape seed meal	88.7	0.74	286	4,611	2,843	2,371	1,674
			0.66	254	62			
CX0050	Copra meal, expeller	91.2	0.76	150	4,767	2,977	2,050	1,710
			0.69	137	62			
CX0080	Linseed meal, extracted	88.6	0.88	294	4,610	3,425	2,853	1,980
			0.78	260	74			
CX0090	Linseed meal, expeller	90.4	0.94	273	4,882	3,657	3,061	2,115
			0.85	247	75			
CX0100	Palm kernel meal, expeller	90.6	0.79	92	4,803	3,137	2,610	1,778
			0.72	83	65			
CX0120	Sesame meal, expeller	93.9	0.95	387	4,956	3,767	3,047	2,127
			0.89	363	65			
CX0130	Soybean meal (46)	87.6	0.93	413	4,659	3,621	2,897	2,093
			0.81	362	78			
CX0140	Soybean meal (48)	87.8	0.94	436	4,703	3,768	2,992	2,115
			0.83	383	80			
CX0150	Soybean meal (50)	87.6	0.93	456	4,697	3,727	2,948	2,093
			0.81	399	79			
CX0160	Sunflower seed meal, non	88.7	0.59	223	4,626	2,320	1,916	1,328
	decorticated, extracted		0.52	198	50			
CX0170	Sunflower seed meal,	89.7	0.64	273	4,628	2,557	2,084	1,440
	partially decorticated, extracted		0.57	245	55			

Bold print: per kg DM Normal characters: per kg as fed or digestibility coefficent %

Organic components									Minerals		
g/kg/%		g/kg							g/kg		
OM, Omd	CP, CPd	Lysine	CF	NDF	ADF	ADL	EE	Starch	P	Ca	Mg
966	223	15.20	40	104	42	2	68	504	4.1	1.3	
82	83										
941	395	24.50	59	125	73	12	203	0	6.3	3.6	
79	85										
963	172	6.80	167	310	201	62	479	0	5.8	3.0	
74	79										
933	546	17.80	76	159	96	28	38	0	6.3	2.2	
87	90										
934	551	17.90	134	225	157	51	10	0	6.3	2.2	
85	87										
921	380	20.30	139	319	221	108	26	0	12.9	9.4	
64	80										
932	225	5.90	141	546	286	66	89	0	5.9	1.3	
65	71										
934	359	13.40	110	257	156	66	34	0	9.0	5.0	
77	87										
935	342	12.90	113	259	157	67	90	0	9.1	4.7	
78	85										
954	163	4.40	197	726	445	134	94	0	6.1	3.1	
68	60										
879	463	10.90	64	201	106	19	118	0	12.6	18.1	
79	89										
926	494	30.40	70	142	85	5	19	0	7.1	3.9	
83	89										
927	516	31.70	68	139	83	8	21	0	7.1	3.9	
83	90										
928	539	33.00	44	102	55	4	17	0	7.1	3.9	
83	90										
930	312	11.30	287	463	330	113	23	0	11.3	4.4	
52	76										
925	373	13.20	276	400	276	92	19	0	12.0	4.5	
57	78										

Appendix 16.1. Microminerals content of forages (INRA, 1989)[1]

		n	Cu	Zn	Mn	Mb
Green forages						
Natural grasslands						
1st growth	grazing stage	9	7.4	48.0	149.0	0.87
1st growth	heading	9	5.9	36.0	148.0	0.83
1st growth	flowering	9	5.0	34.0	141.0	0.75
Cocksfoot						
1st growth	vegetative stage[2]	7	7.5±2.8	32.0±9.0	112.0±32.7	2.28±0.36
	heading	32	6.0±1.0	23.0±5.1	105.0±49.4	1.49±0.84
	flowering	10	4.8±1.1	18.0±4.9	91.4±45.0	0.94±0.22
2nd growth[3]		25	6.8±1.1	22.2±3.7	129.3±62.9	2.55±0.47
3rd growth[3]		14	6.5±0.9	25.2±2.0	128.4±48.5	3.37±0.79
4th growth and other[3]		9	8.7±0.9	30.8±3.9	193.9±66.5	-[4]
Meadow fescue						
1st growth	vegetative stage[2]	11	5.4±1.5	23.8±6.2	90.5±30.1	-
	heading	8	4.8±1.3	19.5±4.3	86.5	0.87
2nd growth[3]		11	5.7±1.3	27.1±7.9	118.3±35.9	-
3rd growth[3]		9	5.7±0.9	21.8±7.0	96.0±31.4	-
4th growth and other[3]		7	6.6±0.4	27.1±10.8	115.0±73.5	-
Tall fescue						
1st growth	vegetative stage[2]	38	6.5±1.3	38.0±13.3	81.3±48.0	1.14±0.60
	heading	30	5.1±2.5	20.9±7.9	77.9±43.2	0.80±0.34
	flowering	6	3.8±1.5	23.0±20.6	93.5±34.2	-
2nd growth[3]		24	5.6±1.4	24.2±14.2	113.1±60.3	0.53±0.41
3rd growth[3]		31	5.9±1.0	27.8±13.6	47.3±52.9	1.08±1.06
4th growth and other		30	6.3±1.2	22.8±9.3	131.0±58.2	0.76±0.71
Perennial ryegrass						
1st growth	vegetative stage[2]	18	5.2±1.7	23.9±9.5	84.7±29.0	1.60
	heading	17	4.0±1.3	19.5±9.5	74.0±25.0	1.01±0.48
2nd growth[3]		15	5.2±1.8	26.5±8.2	148.4±45.4	-
3rd growth[3]		10	6.0±0.9	37.0±9.6	125.0±22.2	-
4th growth and other[3]		12	6.9±1.0	33.8±9.2	151.3±65.2	-
Italian ryegrass						
1st growth	vegetative stage[2]	16	8.1±2.0	32.2±6.6	85.1±38.4	-
	heading	13	5.0±1.4	23.8±7.5	79.6±41.7	-
2nd growth[3]		13	5.8±1.0	32.7±8.8	133.8±45.4	-
3rd growth[3]		15	7.2±1.3	32.2±7.5	139.0±32.7	-
4th growth and other[3]		4	6.8±2.0	31.8±6.7	121.0±23.4	-

Appendix 16.1. Continued.

		n	Cu	Zn	Mn	Mb
Timothy						
1st growth	vegetative stage[2]	22	5.4±2.1	37.4±13.8	77.5±34.1	1.30±0.60
	heading	17	3.8±1.0	25.3±10.7	59.7±36.1	1.05±0.41
	flowering	4	3.1±0.8	22.3±6.2	27.7±10.0	1.00
2nd growth[3]		15	5.1±0.8	24.5±12.7	73.0±36.5	0.75±0.28
3rd growth[3]		8	5.6±0.8	21.0±7.1	74.1±36.0	1.96
4th growth and other[3]		4	6.6±1.4	27.0±2.2	113.8±42.0	0.95
Lucerne						
1st growth	vegetative stage	6	8.8±0.5	32.3±3.1	26.7±1.2	1.30±0.64
	blooming	12	7.5±1.3	22.9±4.3	25.5±10.5	1.07±0.32
	flowering	19	7.7±2.0	22.0±5.9	27.5±9.3	0.56±0.40
2nd growth		27	8.5±2.1	22.3±5.3	52.7±36.0	0.47±0.42
3rd growth		17	8.6±1.5	24.1±4.8	43.9±35.3	0.44±0.31
4th growth and other		16	8.9±1.5	22.8±3.3	36.6±24.2	0.77±0.09
Hays						
Natural grasslands						
1st cut		454	5.2±0.5	29.1±0.5	158.2±5.3	0.63±0.04
Italian ryegrass						
1st cut		23	4.9±0.3	26.5±1.4	110.0±14.5	-
Lucerne						
1st cut		23	7.1±0.3	24.6±2.1	29.0±2.4	-
2nd cut		19	7.5±0.3	23.7±1.1	-	-
Barley straw		6	3.1±0.9	7.3±3.9	17.6±9.2	-
Corn (maize) silage		32	6.1±0.3	26.0±1.6	55.6±8.7	-
Beets			7.0	28.0	-	-

[1] For the ingredients: see tables INRA-AFZ (Sauvant *et al*., 2004).

[2] Vegetative stage: before or at heads 10 cm high above the ground.

[3] Age of regrowth between 4 and 9 weeks.

[4] - = data unavailable.

Appendix 16.2. Vitamins content of some feeds (IU/kg dry matter) (INRA, 1989)

	Vitamin A	Vitamin D	Vitamin E
Green forages of natural rangelands and gramineas	25,000	30	17
Hays			
Natural rangeland (fresh)	6,000	600	10
Natural rangeland (stocks)	1,500	-[1]	-
Italian ryegrass	116,000	2,000	-
Annual ryegrass	48,000	-	210
Lucerne	46,000	600	11
Cereals (grains)			
Barley	1000	-	25
Corn (maize)	1000	-	25
Sorghum	-	-	12
Wheat	-	-	17
Oat	-	-	15
Silages			
Maize	6,000	300	-
Rye	23,000	-	-
Sorghum	14,000	-	-
Straws			
Oat	1000	700	-
Wheat	1000	700	-
Oil meals			
Soya	-	-	7
Sunflower (expeller, decorticated)	-	-	12
Cotton (expeller, 41% proteins)	-	-	35
Cereal by-products			
Wheat bran	1000	-	21
Rice bran	-	-	66

[1] - = data unavailable.

Appendix 16.3. Main organic sources of mineral supplements (INRA, 2007)

Mineral sources	P (%)	Ca (%)	Mg (%)	Other elements (%)
Dicalcium phosphate anhydrate (dibasic)	20-22	28	-[d]	-
Dicalcium phosphate hydrate (dibasic)	17.5	23	-	-
Ammonium phosphate (monobasic)	27	-	-	N 12
Ammonium phosphate (dibasic)	23	-	-	N
Magnesium phosphate	13-15	-	24-28	-
Monocalcium phosphate	22-24	18-21	-	-
Monodicalcium phosphate	20	20	-	-
Monosodium phosphate anhydre	25.5	-	-	Na 19
Monosodium phosphate hydrate	20	-	-	Na 16
Triple Mg, Ca, Na phosphate	17	8	5	Na 13
Calcium carbonate (limestone)	-	35-38	2-4[a]	-
Calcium and Magnesium carbonate (dolomitic limestone)	-	22	10	-
Calcium carbonate anhydre	-	36	-	Cl 14
Magnesium oxide CP [b]	-	-	64	-
Magnesium oxide [c]	-	-	55-59	-
Magnesium hydroxide	-	-	38-39	-
Magnesium sulphate hydrate	-	-	17	S 22

[a] = only for carbonate from sea origin (maërl, lithothamnium).

[b] CP = chemically pure.

[c] Granulometry lower than 500 µm.

[d] - = data unavailable.

Appendix 16.4. Sugar and starch content of forages (% dry matter) (INRA, 2007)

Categories of forages	Sugars[1]	Starch
Green forages		
Ryegrass		
Seeded in the year	3-10	-[3]
1st growth: leafy stage	10-15	-
elongation	10-20	-
heading	10-20	-
flowering	10-15	-
Regrowth with heads	10-15	-
Regrowth with leafs	5-10	-
Other grasses		
Seeded in the year	3-8	-
1st growth	5-10	-
Regrowth	4-8	
Lucerne and red clover[2]		
1st growth: early blooming	6-10	Traces
late flowering	3-5	-
2nd and 3rd growth	3-6	-
White clover	3-4	-
Corn (maize) crop plant		
Milk stage (24% DM)	15	17
Dough stage (29% DM)	11	26
Flint stage (34% DM)	9	30
Flint stage >35% (39% DM)	7.5	32
Cabbages	20-30	-
Conserved forages		
Hays 1st growth		
Natural grasslands	4-8	-
Ryegrass	8-15	-
Other grasses	3-8	-
Legumes	2-4	-
Hays late summer regrowth	3-5	-
Grass silages		
Silages without additive	0-2	-
Silages with efficient additive		
ryegrass	2-6	-
other species	1-2	-
Corn (maize) silages		
Milk stage (25% DM)	14	17
Dough stage (30% DM)	11	25
Flint stage (35% DM)	9	29
Flint stage (40% DM)	7.5	31

Appendix 16.4. Continued.

Categories of forages	Sugars[1]	Starch
Roots and tubers		
Beets	62	-
Turnips	40	-
Potatoes tuber	-	60-65
Swede roots	63	-

[1] Sugars mean water soluble carbohydrates (glucose, fructose, saccharose, etc.) in most feedstuffs, but fructosannes should be added in the case of grasses, inulin for Swede roots, etc.

[2] Two points should be added for red clover.

[3] - = data unavailable.

Appendix 16.5. Ether extract of green and dehydrated forages (Agabriel, 2007)

These contents are considered to be unchanged for corresponding silages harvested without or after pre-wilting, divided by 1, 5 for wilted silages and divided by 2 for corresponding hays (INRA, 2007).

Categories of forages	Ether extract (g/kg DM)
Natural grasslands and grasses	
Seeding year, whatever the stage	30
Grazing year	
1st growth	
Early grazing	35
Leafy	31
Heads at 10 cm	27
Early heading	25
Heading	23
Late heading	21
Early flowering	18
Flowering	16
Late flowering	15
Regrowth	
Whatever the age and the cycle	25
Legumes	
Lucerne	
1st growth	
Vegetative stage at 30 cm	36
Vegetative stage at 60 cm	32
Early blooming	30
Blooming	28
Early flowering	25
Flowering	23
Regrowth	
Whatever the age and the cycle	30
Red clover	
1st Growth	
Vegetative	33
Early blooming	30
Blooming	27
Early flowering	25
Flowering	23
End of flowering	21
Regrowth	
Whatever the age and the cycle	30
White clover	
Whatever the age and the cycle	30
Sainfoin	
Whatever the age and the cycle	30

Appendix 16.5. Continued.

Categories of forages	Ether extract (g/kg DM)
Cereal crop plants	
Maize	
Early grain formation stage	22
Milk-dough	25
Dough-flint	30
Flint	30
Barley	
Flowering	20
Milk	25
Milk-dough	30
Dough	30
Wheat	
Whatever the age and the cycle	30
Oat	
Early elongation	38
Early heading	30
Flowering	25
Milk-dough	25
Dough	30
Rye	
Early elongation	25
Early heading	25
Heading	25
Flowering	25
Milk-dough	30
Dough	35
Sorghum	
1st Growth	
Before early heading	35
Early heading	31
Heading	29
Flowering	27
Dough	30
Regrowth	
Leafy	35
Headed	30
Legume seeds	
Soya	
Early varieties	
Pod formation	25
Early seed formation	50
Seed maturity	75

Appendix 16.5. Continued.

Categories of forages	Ether extract (g/kg DM)
Legume seeds	
Soya	
Late varieties	
Early flowering	20
Flowering	20
Pod formation	25
Early seed formation	35
Peas	
Seed formation	30
Seed yellowing	35
Faba bean	
Flowering	30
Pod formation	30
Hard seed	25
Early maturity of seed	20
Lupin seed	
Flowering	25
Early seed formation	30

Appendix 16.6. Fat acids composition of some vegetable oils (Sauvant *et al*., 2004)

Fat acids (% total FA)	Rapeseed	Coprah	Palm	Soya	Sunflower
C6+C8+C10	-[1]	13.1	-	-	-
C12:0	0.2	46.4	0.3	-	0.2
C14:0	0.1	17.7	0.6	0.1	0.2
C16:0	4.2	8.9	43.0	10.5	6.3
C16:1	0.4	0.4	0.2	0.2	0.4
C18:0	1.8	3.0	4.4	3.8	4.3
C18:1	58.0	6.5	37.1	21.7	20.3
C18:2 ω-6	20.5	1.8	9.9	53.1	64.9
C18:3 ω-3	9.8	0.1	0.3	7.4	0.3
C20:0	-	0.5	0.4	0.3	-
C20:1	-	-	-	0.2	-
C22:1	0.4	-	-	0.3	-

[1] - = data unavailable.

Glossary

Additives	These are substances, microorganisms or mixes that are included in manufactured concentrate feeds or premixes to improve the technologic characteristics of the feeds or improve animal performance (Chapter 9).
Adipose depots	All fatty tissues of an animal. These tissues primarily store lipids (body reserves). Body condition scores ranging from 0 (very thin) to 5 (very fat) provide a rough estimation of these deposits (Chapter 1, 2, 3, 4, 5, 6, 7 and 8).
Agonistic interactions	Interactions designed to resolve conflict with another animal (e.g. threats, aggression, and submission).
Amino acids	Basic units (20 in number) of proteins, they have a minor acidic function. Similar to monogastrics (e.g. swine) and other herbivores (e.g. cattle), horses cannot synthesise (or may but at a very low rate) about a dozen of these compounds, which are said to be indispensable or essential (Chapter 1).
Anovulatory period (also seasonal anoestrus or the winter period of ovarian inactivity)	A period of time without ovulation, primarily in winter but the duration of which is dependent on level of nutrition (Chapter 3).
Anthelmintic	Medical product for treatment of helminths or worms (Chapter 10).
Appetite	The desire to satisfy hunger, the animal's desire for food. The rate of food intake by the animal from the commencement of eating is a good indicator of this factor (Chapter 1 and 12).
Base ration	A ration consisting primarily of forages, but also may contain roots and tubers as well as various by-products (seeds and fruits) of low energy concentration (Chapter 2 and 13).
Body condition	A measure of the fatness of the animal (Chapter 2 and 7).
Body mass	Empty bodyweight (Chapter 1 and 2).
Body reserves	These are primarily fats (lipids) contained in the animal's body, which it may use (mobilise) if food intake is insufficient or store if intake is above requirements (Chapter 1, 2, 3, 4, 5, 6, 7 and 8).
Bran	These are by-products of the cereal grain milling industry consisting principally of fragments of the outer layers and of particles of grain from which the greater part of the endosperm has been removed (Chapters 9 and 16).
Catabolism	Biological degradation of a compound or group of compounds in the organism (Chapter 1).
Cell walls	The complete skeletal structure of the walls of plant cells. It consists of four groups of compounds: cellulose, hemicelluloses, pectic substances and lignin. The approximate estimation of cell wall content is obtained by treating the feed with an aqueous solution containing a neutral detergent (neutral detergent fibre or NDF from Van Soest) (Chapter 1 and 12).

Cellulolytic bacteria Bacteria which hydrolyse cellulose and hemicelluloses in the large intestine (Chapter 1).

Cellulose A basic constituent of plant cell walls composed of long glucose chains. These chains are grouped in fibrils, then fibres, which form a network that gives rigidity to cell walls. It can only be solubilised in concentrated acid (72% sulphuric acid) (Chapter 12).

Colostrum The first milk produced by a mare during the first 12 to 36 hours following foaling. It provides the newborn foal with the necessary immunoglobulins for combating foal illness during the first days of life (Chapter 3).

Compensatory growth An increase in daily weight gain superior to that which the animal would have gained if it had not been previously subjected to a period of feed restriction (Chapter 5).

Complete feed A manufactured feed designed to provide all the necessary nutrients in proportions necessary to meet the nutritional requirements of the animal. They may be used to completely replace traditional diets.

Complete ration A ration that is a mixture of a base ration (forages) and concentrate feeds in a single feed (Chapter 2).

Concentrates (an abbreviation of concentrated feeds) Feeds having a high net energy (UFC) on a dry matter basis and, frequently, a high protein content (MADC). They are:

Single concentrate feeds (Chapter 9) oilseeds, grains (cereals) and fruits, by-products of grains and fruits, as well as roots and tubers, having retained a high energy content (UFC);

Compound concentrate feeds a mixture of single concentrate feeds as well as a varied amount of other feeds (forages) (Chapter 9).

Coproscopy Microscopic examination of faeces to determine the number of strongyle or ascarid eggs. The results are given in eggs per gram (EPG) of faecal matter (Chapter 2 and 10).

Corn gluten This is a dried by-product from the manufacture of maize starch by wet milling (Chapter 9 and 16).

Crude fibre This is the organic residue of compounds obtained by successive hydrolyses (0.26 N sulphuric acid, then 0.23 N potassium hydroxide) according to a modification of the Weende method. This method over-estimates cellulose as the result contains a variable amount of lignin and hemicelluloses (Chapter 12).

Crude protein This measure includes both protein and non-protein (but nitrogen containing) compounds (free amino acids, amides and low molecular weight peptides) Chapter 12.

Defatted meal A feed obtained after the extraction of oil or fat from grains with an appropriate solvent. The resulting product generally contains less than 4% fat (Chapters 9 and 16).

Dehulled meal The dehulling (or dehusking) of grain separates the outer covering that is primarily cell wall material from other constituents of the grain to produce a highly digestible, protein rich feed (Chapter 9 and 16).

Development	Involves all phenomena that result in the formation of an adult horse from fertilisation and which occur through morphological, anatomical and chemical changes (Chapter 5).
Diet	Defines the feeds, manufactured or not, that make up the ration: forage(s) alone (a forage diet); forage plus concentrate (forage based if forage predominates, or mixed diet) (Chapter 2).
Dietary restriction	A temporary reduction in feed intake imposed over a given period of the breeding or production cycle of an animal (Chapter 1, 2, 3, 4, 5, 6 and 8).
Dietetic feeds	These are compounds (plant fibre, amino acids, essential fatty acids, etc.) designed to meet specific nutrient requirements on a temporary basis to relieve digestive or metabolic problems (Chapter 9).
Digestible crude protein (MAD in French or DCP in English)	Crude protein intake minus the nitrogen compounds excreted in faeces. The amount of digestible crude protein in a feed or a ration is calculated by multiplying the total crude protein by its apparent digestibility (Chapter 1 and 12).
Digestible energy (DE)	The energy difference between the gross energy contained in the ingested feed and the energy excreted in faeces (Chapter 1).
Digestive strongyles	Nematode parasites of the digestive tract. They can be differentiated into small strongyles (*Cyathostominae*) and large strongyles (*Strongylus* spp.) (Chapter 2 and 10).
Draft work	This is the product of pulling force and distance travelled (Chapter 6).
Early development of the animal	Capacity of the animal to rapidly progress through its developmental stages. For animals destined for slaughter this implies rapid growth and fattening. For performance animals it implies reaching adult size at a relatively young age (Chapter 1, 5 and 7).
Empty bodyweight (or body mass)	Bodyweight minus the weight of the contents of the total digestive tract (Chapter 1).
Endogenous	Refers to what is produced in the body. Endogenous components passing through the digestive system are constituents of cells sloughed from the walls of the digestive tract (desquamation), digestive secretions (saliva, gastric juice, pancreatic juice) and urea that diffuses from the blood (Chapter 1 and 12).
Expeller (pressed) meal	A feed obtained after fat is extracted from grains under pressure. The resulting product contains from 5 to 10% fat. (Chapters 9 and 16).
Expansion-extrusion	The technological process used in the feed manufacturing industry to treat the combined elements of manufactured feed, or in some cases only the cereal grain portion (semi-extruded). The process involves treating the material to be extruded to an injection of steam and very high mechanical pressure, raising the temperature to about 90 °C, which results in gelatinisation of the starch. The product is forced through a die (extruded) followed by a rapid decompression and a considerable increase in volume: e.g. expansion of the final material. But sometimes no drop in pressure is applied at the end of the process. The final product is only extruded. The processes usually result in an increase in digestibility of the product (Chapter 9 and 12).

Fat	The current term for substances extracted from animal or plant tissues by certain organic solvents used in laboratories. The organic substances extracted from feeds of plant origin by di-ethyl ether or petroleum ether generally over estimate lipid content (Chapter 1 and 16).
Fattening or finishing	An increase over time in bodyweight due in large part to fat tissue accumulation that can be related to an elevated daily weight gain or the advanced age of the animal (Chapter 5 and 7).
Faeces	Solid excrement. It consists of undigested food constituents, bacterial cells and endogenous products (Chapter 12).
Feed contaminants	These are compounds or naturally occurring components of plants that have pharmacological activity and are therefore prohibited by regulation. They may be found in the primary ingredients used to manufacture feeds or introduced in error in the manufacturing process, packaging or transportation (Chapter 9).
Feed contamination	Contaminants may be soil, microorganisms (bacteria or fungi and the end-products of their metabolism), or insects included at the time of harvest or due to improper preservation of forages or primary concentrate feeds (Chapter 9 and 11).
Feed mineral-vitamin supplement	A feed composed of concentrated minerals and vitamins designed as a readily available dietary supplement (Chapter 2 and 13).
Flaking	A technological process used in feed manufacturing to treat cereal grains. The procedure involves submitting the grains to an injection of steam at temperatures of 100-120 °C, under normal or elevated atmospheric pressure for 5 to 30 minutes. The grains are then compressed between fluted rollers (Chapter 9 and 12).
Follicle	An ovarian structure that enlarges as it fills with fluid that serves to expel the ovum at ovulation (Chapter 3).
Food poisoning	This is caused by the accidental consumption of toxic plants or feed contaminated by chemical residues, mycotoxins, or toxins of bacterial origin. Feeding excessive amounts may also be a cause.
Forage	Feed derived from the areal portions of forage plants (leaves, stems, reproductive organs), which may be cultivated or naturally occurring. Plants harvested after flowering contain a certain proportion of seed or grain which may be immature or mature (Chapters 9, 12 and 16).
Follicle Stimulating Hormone (FSH)	One of two gonadotrophins involved in producing follicular growth (Chapter 3).
Growth Hormone (GH)	A protein hormone secreted by the pituitary gland, which acts on body tissues, either directly or via IGF-1, to control metabolism (Chapter 3 and 5).

Glucose	A simple sugar. Even though it is the basic unit of both starch and cellulose it is only present in plants in very small quantities as a free sugar. It is a major absorption product if present in the intestine in significant amounts (Chapter 1) and it is synthesised in the liver from propionate (gluconeogenesis) and other glucogenic compounds.
Glycaemia	The concentration of glucose in the animal's blood. It is higher in horses (0.8 to 1.2 g/litre) than in ruminants (Chapter 1 and 6).
Glycogen	The reserve form of glucose in liver and muscles (Chapter 1 and 6).
Gonadotrophins	These are two protein hormones secreted by the anterior pituitary gland and influence gonadal activity (Chapter 3).
Growth	Increase in bodyweight (e.g. daily live weight gain or average daily gain) and size of the animal (e.g. wither height) as a function of time (Chapter 5).
Hemicelluloses	All cell wall polysaccharides are soluble in alkaline or relatively dilute acid solutions. Xylans are the most important in grasses. They have chemical bonds with lignin which can be broken with alkaline treatment (soda, ammonia) in the case of straws and other lignified by-products (Chapter 12).
Horse digestible crude protein (MADC)	The quantity of digestible protein that provides amino acids. The MADC content of a feed or ration is calculated by successively multiplying the crude protein content by the apparent protein digestibility then by a correction factor that varies depending on the type of forage or concentrate. This correction factor depends on the true digestibility of the forage crude protein in the small and large intestine and the rate of absorption in the form of amino acids (Chapter 1 and 12).
Horse feed unit (UFC)	The quantity of net energy in one kg (gross) of reference barley (870 g of dry matter) for the horse at maintenance. 1 UFC = 2,250 kcal of net energy for maintenance (Chapter 1 and 12).
Ingestibility	The amount of forage spontaneously ingested by the horse fed free choice.
Insulin-like growth factor 1 (IGF-1)	A protein with a similarity to insulin that is secreted by many tissues but particularly the liver and which is controlled by GH (Chapter 3 and 5).
Imbibition	The process by which a feed (e.g. dehydrated beet pulp) rapidly absorbs water in greater or lesser quantities (Chapter 9).

Impregnation	The concept of imprinting, developed from observations on hatchling birds (geese, chickens), defined by Lorenz (1935) as the 'acquisition of the object' on the target animal using 'socially instinctive reactions'. For the young animal, imprinting involves following the first mobile object (the mother in a natural situation) encountered after birth. This mechanism has been recognised as the basis for later selection of social and sexual partners. Based on the imprinting phenomena illuminated by studies of young fowl, an American veterinarian, Robert Miller, has developed a method referred to as 'impregnating the foal' (Miller, 1991). Using this method the foal must be manipulated all over its body and exposed to various objects that may frighten it, such as clippers and halter, objects the foal will soon have to deal with, as soon as possible after birth, even before it has nursed. According to the author this exposure will be permanently registered in the foal's memory and will make future training and handling easier. Scientists agree on the fact that, using this method, imprinting of the foal in its true sense does not occur. No scientific study has demonstrated the positive effects claimed by the author (Henry *et al.*, 2009) (Chapter 15).
Intake capacity of the horse	Often mistakenly referred to as appetite, this is the quantity of feed a horse will voluntarily ingest when fed *ad libitum*. It is determined by the energy expended, thus the level of production. It also depends on anatomical (size of digestive tract compartments, etc.) and physiological (appetite, physiological balance, etc.) characteristics (Chapter 1).
Intake	The quantity of feed that the animal must ingest to meet its nutritional requirements. Horses, like humans, have the characteristic of eating a quantity of food above requirements, over a lengthy period if food is available free choice (Chapter 1 and 2).
Intra-cellular constituents	All organic constituents situated in the interior of plant cells (as opposed to those in the cell walls): sugars, starch, organic acids, free amino acids, amides, proteins, lipids, etc. They can be, but not all (starch) completely extracted using a water solution containing neutral detergent (Chapter 12).
Joule	Physical unit of work (Chapter 1). 1 joule = 4.18 calories.
Kilogram metre	Physical unit of work (Chapter 1 and 6).
Lactic acid – lactate	A product of the anaerobic metabolism of glucose while under intense work effort.
Luteinizing hormone (LH)	One of the two gonadotrophins inducing ovulation (Chapter 3).
Lignin	A complex, high molecular weight polymer of dense structure that is an intimate part of the thick cell wall of plants and retards their degradation by microbes in the large intestine. It is identified as the organic residue after all other constituents have been solubilised (Chapter 12 and 16).

Lignocellulose	It is the residue obtained after a feed is hydrolysed in 0.5 N sulphuric acid in the presence of a detergent (acid detergent fibre, ADF). In addition to lignin and cellulose, it contains some hemicelluloses as well as other constituents (Chapter 12 and 16).
Lipids	Generic name for fats. The most important of these, by far, are the glycerides which are esters of fatty acids (Chapter 1, 3, 5, 6, 12 and 16).
Long-chain fatty acids	These are monoacids composed of a linear carbon chain, which, with glycerol, make up lipids or, more correctly, the glycerides. Unsaturated fatty acids containing 18 carbon atoms are by far the most important in foods of plant origin (Chapter 1, 3, 6, 12).
Maintenance requirements	The requirements to meet physiological expenditures of the animal at rest, in a thermal neutral environment, under normal production conditions, at a constant bodyweight and body composition (Chapter 1).
Maintenance	In maintenance the animal maintains a constant weight and body composition while not producing any growth, milk or work (Chapter 1).
Manipulation	Palpating the horse's body at various sites to determine body condition (Chapter 2).
Metabolic weight ($BW^{0.75}$)	Bodyweight to the 0.75 power. This function illustrates the fact that the energy cost of maintenance and intake capacity varies less that bodyweight. It allows better comparisons of requirements and intake capacity of animals or of species of very different sizes (Chapter 1).
Metabolism	The total of all chemical and biological transformations performed in an organism (Chapter 1).
Metabolisable energy (ME)	This is a measure of the energy potentially available by the animal after digestion of the feed and nutrient absorption from the digestive tract. It corresponds to the difference between the digestible energy of the feed and losses of part of the energy due to methane production through fermentation by microbes in the large intestine and part in the form of urea produced through partial utilisation of the absorbed, terminal products of digestion and excreted by the kidneys (Chapter 1).
Middlings	These are by-products of the bread milling industry consisting principally of fragments of the outer layers and of particles of wheat grain from which less of the endosperm has been removed than in wheat bran (Chapters 9 and 16).
Milk replacer	A dry milk feed, which after dilution with water provides a milk substitute feed.
Muscle fibre	The structural unit of skeletal muscle (Chapter 6).

Net energy (NE)	The amount of energy necessary to meet the energy costs of maintenance and production of the animal. It corresponds to the metabolisable energy minus the energy lost as extra heat caused by the consumption and digestion of food and the metabolism of nutrients. It is expressed as horse feed units (UFC) (Chapter 1, 12 and 16).
Newton	Physical unit of force (Chapter 6).
Non-protein nitrogen (NPN)	Nitrogen components in feeds which are not part of proteins: free amino acids, amides, etc. Such soluble nitrogen constituents can be isolated in 80% ethanol. This term also includes industrial sources of non-protein nitrogen such as urea and ammonium salts, distillation residues, etc. (Chapters 1, 9 and 12).
Nutrients	Blood constituents (glucose, etc.) derived from the terminal products of digestion in the digestive tract (Chapter 1).
Nutritional supplements	These are compounds (carbohydrates, amino acids, electrolytes, etc.) fed singly or in mixtures of varying complexity, to deal with temporary changes in nutritional status for brief, critical periods (Chapter 9).
Ovulation	Release from the follicle of an ovocyte, which may become fertilised (Chapter 3).
Oxygen debt	During a period of recovery following work oxygen consumption remains elevated for a time the length of which depends on the intensity of the preceding work. The difference between the VO_2 measured during recovery and the VO_2 measured at complete rest is termed the oxygen debt. Contrary to what is generally believed, the oxygen debt does not serve to replace the oxygen used by the animal during exercise. Oxygen debt is associated with the replenishment of energy reserves that have been depleted and the elimination of lactic acid that has accumulated during the exercise (Chapter 1 and 6).
Palatability	The stimulating value of a feed, which is dependent on its organoleptic (aroma, taste, etc.) and physical (size, tenderness, etc., characteristics which influence the intake of food by the animal (Chapter 9 and 12). It equally relies on the internal state of the animal and its previous exposure to the feed.
Pectic substances	A complex group of polysaccharides localised in the middle lamellae where they act as intercellular cement in the outer wall of plant cells. They are abundant in fruits and roots and are soluble in water solutions containing neutral detergent (Chapter 12).
Photoperiod	Variation in day length as a function of season (Chapter 3).
Physiological expenditure or net requirements	Total amount of energy or nutrients lost, gained or secreted by an animal in good health, in an optimal environment and receiving a nutritionally balanced diet (Chapter 1).
Production requirements	The requirements to meet physiological expenditures associated with product development: foetus, milk, weight gain, or muscular work in average (e.g. standard) environment (Chapter 1).

Progesterone	A hormone secreted by the *corpus luteum*, which develops on the follicle after ovulation (Chapter 3).
Proteins	Organic macromolecules composed of amino acids. Plant proteins have an almost constant amino acid composition that is relatively well balanced. The proteins of seeds and grains are a mix of variable proportions depending on species and amino acid composition (Chapters 1 and 12).
Pulling force	Work produced by a horse when moving a mass (Chapter 6).
Ration	This defines the daily quantity of feed composed of different ingredients formulated to meet the nutritional needs of the animal and promote its well-being (Chapters 2 and 13).
Rationing	A process consisting of feed selection and calculation of the amounts necessary to feed that will provide animals all the nutrients that they require (Chapter 2 and 13).
Recommended daily allowances (or recommended nutrient intakes)	The quantity of nutrients the animal should ingest in order to attain the desired level of performance with its innate production capacity. In most situations, the recommended allowances meet physiological demands or basic requirements plus provide a margin of safety. This can be referred to as feed requirements (Chapter 1). However, in certain circumstances, all physiological expenditures may not be met, in which case body reserves will be mobilised (e.g. mares in early lactation, Chapter 3, working horses, Chapter 6).
Reinforcement	An event that increases the likelihood that behaviour will be repeated. This reinforcement concept is closely linked to an underlying motivation. There are two types of reinforcement. In positive reinforcement a pleasant stimulus is used (e.g. food is a positive reinforcement to a hungry individual) which then produces the desired behaviour. In negative reinforcement an unpleasant stimulus is removed when the desired response occurs. An example might be that a horse is encouraged to jump a small fence when a light flashes in the take-off area signalling that an electric shock will be applied if the horse does not jump. Jumping the fence will avoid the shock. (Richard-Yris *et al.*, 2004; Sankey *et al.*, 2010) (Chapter 15).
Roughages	Feeds such as forages (green or preserved), roots or tubers and their by-products and harvesting residue (straw, corn stover, etc.) (Chapter 9).
Single concentrated feeds (or feed materials)	These are the raw materials or ingredients from primary agricultural production (seeds or grains) or their by-products after industrial processing, which are included in manufactured mixed feeds (Chapter 9).
Soluble carbohydrates (in water) or cytoplasmic sugars	They include free sugars and fructosans. The principal ones are glucose, fructose, saccharose (beet sugar) and minor sugars. Fructosans are short chains of fructose linked to an initial glucose unit. They accumulate at the base of the stem of certain grasses, especially ryegrass, which explains their relative abundance in soluble carbohydrates (Chapter 12 and 16).

Starch	A storage carbohydrate composed of two glucose polymers, amylose, in linear form, and amylopectin, in branched chain form. It is found as granules in storage tissues of grains and is the principal constituent of certain seeds and roots.
Stereotypies	A behaviour 'repeated and unvarying, without apparent benefit or function'. The activity is normally locomotive in nature (e.g. weaving, head bobbing) or oral (e.g. cribbing, tongue or lip movements). Stereotypies, which are not seen in horses managed in natural environments, represent a reaction to unusual stress in certain individuals and may, in part, be due to a genetically based sensitivity to environmental conditions.
Suckling foal	A young draft horse foal nursed by its mother (Chapter 7).
Supplement feed	A manufactured compound feed designed to complement and balance a forage-based diet in order to provide all the nutrient elements necessary to meet the animal's nutritional requirements (Chapter 9).
Thermal neutral zone (TNZ)	The ambient temperature zone in which the horse does not use extra energy in order to maintain a constant body temperature of 38 °C.
Total requirements	The sum of maintenance and production requirements (Chapter 1).
Trace elements	Mineral elements which are active at very low doses in the metabolism of living organisms (enzyme systems, hormones) (Chapter 1, 2, 12, 13 and 16).
Transition feeding	A short duration period (from a few days to 2-3 weeks) in which the type of feed or the amount fed to the animal changes progressively (Chapter 2).
Vitamin-mineral mix (see also feed mineral vitamin supplement)	Supplemental feed consisting principally of vitamins and minerals (Appendix 1), containing at least 40% ash and supplemented with vitamins (Chapter 2 and 13).
Volatile fatty acids (VFA)	These are a mixture of acetic, propionic, and butyric acids and in much lesser quantities, isobutyric, valeric, isovaleric acids, etc., that are produced by the microbial population in the large intestine. In general the quantity of each acid in a mixture is expressed as its molar percentage.
Voluntary intake of forage (neologism)	The quantity (dry matter) of forage that is eaten when it is provided free choice as the only feed. Intake of different forages can be compared when they are provided to animals with the same intake capacity (Chapter 1 and 12). Intake fundamentally varies inversely with the degree of lignification of the plant cell walls and the filling effect it has on the digestive tract: large intestine (but to a lesser extent than in ruminant) (Chapter 2). It also depends on the palatability of the feed.

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Further reading

Preliminary comments

This book presents the new concepts and their applications in equine nutrition which have been established mainly on long term research programs carried out at INRA. These new knowledge have been already argued in the publications which have been already published in scientific journals. Hence, this book is not a synthesis of the literature. However, a list of a selection of references is displayed for readers who would eventually increase their knowledge. Few references quoted sometimes across chapters are listed at the end of the chapters and again in this long list as well.

All the references are classified in three large sections. In the first section large information come from books or synthesis or proceedings dedicated to large scientific areas. The two following sections are focused on specific fundamental or applied information published mainly in journals.

Hence, the readers can easily find out the information using author's names when they are already quoted in the text and one or two additional key words dealing with the topic for example: Smith – feeds – prediction or only with key words. This is quite similar when someone is tracking information using internet.

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9. Feeds additives, dietetic feeds, nutritional supplements

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