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FEEDING STANDARDS FOR ENERGY AND PROTEIN FOR HORSES IN FRANCE

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Thanks to the increase in knowledge since 1965 in the USA and Europe, INRA created new feeding systems for horses in France in 1984: the UFC[(1)] system for energy and the MADC[(2)] system for protein (INRA, 1984). These systems provide sets of tables that give the nutritive value of the feeds and the nutrient requirements of the horses, respectively. Both are expressed according to the same feed evaluation systems, either UFC for energy or MADC for protein. The goals of these systems are to allow:

1) an accurate comparison of the nutritive value of feedstuffs;
2) the formulation of well balanced rations to achieve a production goal;
3) the prediction of the animal performance when amount and quality of rations are known.

The validity of the UFC and MADC systems was tested through many feeding trials using mares, growing horses and working horses to create the new French feeding standards. These systems and the proposed feeding standards were updated in 1990 by the INRA group on the basis of further experiments and feeding trials, which focused on energy metabolism and mare and growing horse nutrition. In the 1990s, research was conducted at INRA on routine methods for predicting the net energy values of feeds and on nitrogen digestion. These systems are official feeding standards in France (INRA, 1990), and they are used in an increasing number of western European countries[(3)] and in some eastern European countries[(3)], with or without local adaptations (Miraglia and Oliveri, 1990; Staun, 1990; Smolders, 1990; Austbo, 1996). But there is still an increasing demand for a new scientific basis of equine nutrition and feeding management in the world to improve equine nutrition evaluation as pointed out by Pagan and Jackson in the proceedings of the 1998 KER Equine Nutrition Conference for Feed Manufacturers (KER, 1998).

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(1) UFC : Horse Feed Unit (Unité Fourragère Cheval in French)
(2) MADC : Horse Digestible Crude Protein (Matières Azotées Digestibles Cheval in French)
(3) INRA 1990 Handbook has been translated and edited in Spanish 1993, in Italian 1994, in Romanian 1996, English and Polish translations are in progress. Portugese translation may occur.

Feed Evaluation Systems

The Horse Net Energy System (UFC)

A new horse net energy system was proposed and introduced in France (INRA, 1984) to evaluate and express the energy value of feeds and to recommend energy allowances for horses. The scientific concepts, the bases and the structure of the UFC system were precisely established and validated through several studies (indirect calorimetry and feeding trial) carried out on horses and ponies (Vermorel and Martin-Rosset, 1997). The mode of utilization of the UFC system for rationing horses was described in detail in a handbook devoted to end-users (INRA, 1990).

The French horse net energy system is based on two concepts:

1) maintenance is the major component of energy expenditure in most horses - 50 to 90% (Martin-Rosset et al., 1994);
2) the net energy (NE) value of nutrients for both maintenance and work (physical activity) depends on the free energy (ATP) produced by oxidative catabolism (Vermorel et al., 1984; Vermorel and Martin-Rosset, 1997).

The NE value of feeds is calculated through a stepwise procedure (Figure 1) from:

1) their gross energy (GE) content;
2) their digestible energy (DE) as measured in horses;
3) the ratio between metabolizable energy (ME) and DE as determined in horses;
4) the efficiency of ME utilization for maintenance (km) :

$$NE = ME \times km \text{ or } NE = DE \times \frac{ME}{DE} \times km.$$

The km is computed from the energy cost of eating, the assumed proportions of absorbed energy supplied by the various nutrients and the efficiencies of nutrient energy utilization:

For concentrate feeds :

$$Km = 0.85\, E_{Gl} + 0.80\, E_{LCFA} + 0.70\, E_{AA} + (0.63 \text{ to } 0.68)\, E_{VFA}$$

For forages :

$$Km = 0.85\, E_{Gl} + 0.80\, E_{LCFA} + 0.70\, E_{AA} + (0.63 \text{ to } 0.68)\, E_{VFA} - 0.14\,(76.4 - ED)$$

where E is the percentage of absorbed energy supplied by glucose or lactate (Gl), long chain fatty acids (LCFA), amino acid ME (AA) and volatile fatty acids (VFA). ED is energy digestibility (%) of the feed. The last term [- 0.14 (76.4 - ED)] of the prediction equation corresponds to the cost of eating for forages.

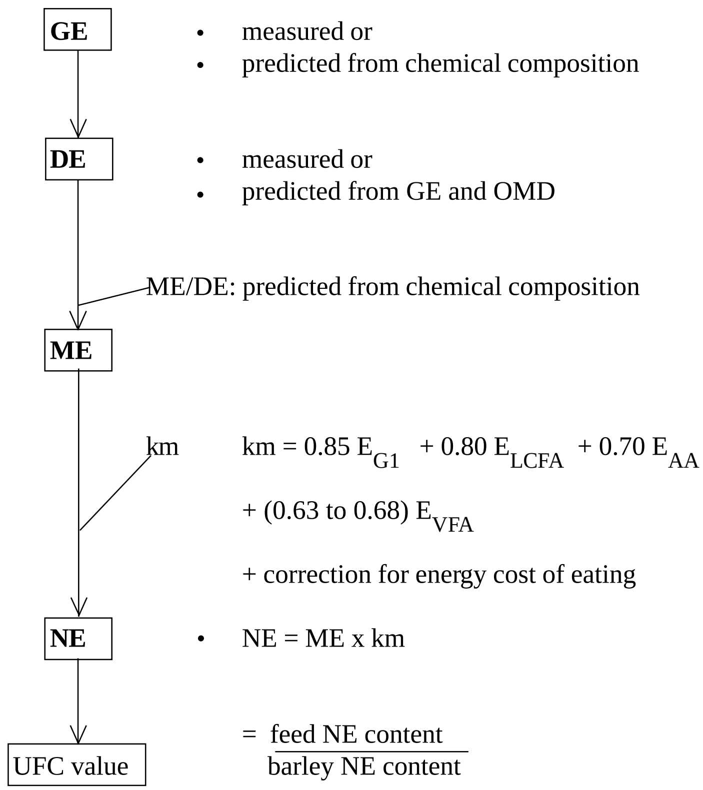
As a result, **NE content of a reference feed, such as barley in Europe, accounts for 2.250 Mcal*/kg fresh material for a horse at maintenance** and is stated:

Net energy content of one kg of standard barley (87 % DM) is :

GE = 3.854 Mcal*/kg fresh material
OMD[1] = 0.83 ED = 0.80 DE = 3.076 Mcal*/kg
ME/DE = 0.931 ME = 2.864 Mcal*/kg Km = 0.785
NE = 2.248 Mcal*/kg, e.g. NE = 2.250 Mcal*/kg

* 1 Megajoule = 4.19 Mcal [1]Organic Matter Digestibility

Figure 1. Stepwise procedure to determine the net energy value of feeds in the UFC system (Vermorel & Martin-Rosset, 1997)



In France and in most countries of western Europe, the NE content of feed is related to that of a reference feed (barley) and expressed in feed units, which allows easy comparison of the feeds and their substitution. For horses, INRA proposed the Horse Feed Unit (Unité Fourragère Cheval or UFC in French):

$$\text{UFC value of a feed} = \frac{\text{NE content of feed}}{\text{NE content of barley}}$$

In 1984 and then in 1990, the NE content was stated by INRA to be 2.200 Mcal/kg and the INRA feed composition and nutritive value tables and nutrient requirement tables were created referring to this value of barley (Vermorel et al., 1984 ; Vermorel and Martin-Rosset, 1987).

In the year 2000, one feed unit corresponds to the NE content (2.250 Mcal) of one kg of standard barley (87% DM) for horses at maintenance (Vermorel and Martin-Rosset, 1997). But the energy values in feed tables and nutrient requirements (INRA, 1990) have not yet been changed; as a result the NE referring value of barley is still 2200 kcal/kg. The feed and requirement tables will be adjusted in 2001 in the next expected revision of INRA.

In this paper NE content of one kg of barley is maintained at 2.200 Mcal/kg (INRA, 1990).

Expressed per kg DM, the NE values range from 2.97 Mcal (maize), 2.55 Mcal (barley), 2.22 Mcal (oats), 1.94 Mcal (maize silage), 0.88 Mcal - 1.47 Mcal (hays) to 0.57 Mcal (straw) and the UFC values of feeds range from 1.35 (maize), 1.16 (barley), 1.01 (oats), 0.88 (maize silage), 0.40- 0.67 (hays) to 0.26 (straw).

Although organic matter digestibility (OMD) is the major factor of feed energy value, the further steps from DE to ME, then from ME to NE, increase the discrepancies between feeds. For instance, the DE, ME and NE contents of poor quality grass hay amount to 49%, 41% and 35% of those of barley, respectively.

The UFC system is an empirical model for predicting the NE value of feeds for horses. It does not portend to give the true energy values of feeds but the values are closer than a DE system would predict. It is now well demonstrated that methane and urinary energy losses and utilization of ME for maintenance (or fattening) vary with diet composition in horses as in other species. In a DE system, the energy of protein rich feeds and forages is overestimated (by about 15% for cereal byproducts, 25-30% for oil meals and 30-35% for hays), whereas that of feeds rich in starch is underestimated (Table 1).

Although feed digestibility is the main variation factor of NE value in all existing energy systems, the main limit of accuracy of the UFC system now consists in the percentage of energy supplied by the main nutrients. For instance, digestion in the small intestine seems to vary with starch origin (oats vs. barley, maize or sorghum), grain processing and starch supply (Potter et al., 1992a and 1992b; Meyer et al., 1993). However, significant errors in these estimates have relatively small effects on km. For instance, in the case of wheat bran, a 20% underestimation of glucose supply, involving an increase in the estimate of the VFA supply, causes a 0.4% unit error in km, a relative error of only 0.5% (Vermorel and Martin-Rosset, 1997).

Using km to predict the energy value of feeds for horses in various physiological situations certainly causes errors in the cases of lactation and growth. However, in ruminants the ratio of km to kl (lactation) is relatively constant whatever the feed (Van Es, 1975). The situation could be similar in horses and the NE values of feeds should be similar for maintenance and lactation. Furthermore, energy requirements for lactation account for about 50% of total energy requirements (Doreau et al., 1988). The differences in efficiency of ME utilization for maintenance (km) and fattening (kf) or growth (kpf) are certainly higher than for lactation, especially in the case of forages, but requirements for growth account for only 10 to 30% of total energy requirements in light breeds and 20 to 40% in heavy breeds (Agabriel et al., 1984).

Table 1. Energy values of feeds related to that of barley in a DE system and in the UFC system. Relative difference between the two systems for each feed (Vermorel and Martin-Rosset, 1997).

As fed	DE System	UFC System	DE % NE
Maize starch	116	131	88
Maize	111	115	96
Wheat	108	109	99
Barley	100	100	100
Oat	90	85	105
Wheat feeds, fine	102	94	108
Wheat bran	88	77	114
Wheat bran, coarse	81	71	115
Maize, gluten feed	96	83	116
Pea (seeds)	107	99	108
Fababean (seeds)	102	90	113
Beet pulp, dehydrated	85	74	116
Linseed meal (36% CP)	98	79	124
Soyabean meal (45% CP)	113	91	124
Peanut meal (48-50% CP)	114	87	130
Lucerne hay	70	54	130
Good quality grass hay	64	49	132
Bad quality grass hay	49	35	137

The NE supplied by the feeds of a ration are additive.

Example: A diet composed of 8 kg of grass hay (1.125 Mcal NE/kg fresh material) and 5 kg of barley (2.200 Mcal NE/kg fresh material) supplies 9.00 + 11.00 (respectively) = 20.00 Mcal NE.

The Horse Digestible Crude Protein System (MADC)

The Horse Digestible Crude Protein System is based upon two concepts (Jarrige and Tisserand, 1984 ; Tisserand and Martin-Rosset, 1996):

1) nitrogen value of feedstuffs depends on the amount of amino acids (AA) truly provided by the feedstuffs;
2) the amount of AA provided by feedstuffs depends on the site of digestion in the digestive tract (small intestine vs. large intestine).

Non-protein nitrogen (NPN) may account for 10 to 30% of total nitrogen in forages. In concentrates, NPN is very low. The true digestibility of nitrogen (N) from the small intestine estimated from the studies carried out in the USA and in Europe in the 1970s with markers in slaughtered or fistulated animals (Jarrige and Tisserand, 1984; Martin-Rosset et al., 1994 ; Cuddeford, 1997 ; Potter et al., 1992-1995) or performed recently at INRA with mobile nylon bag technique (MNBT) in fistulated horses (Cordelet, 1990; Macheboeuf et al., 1995-1996) or in Scotland (Moore-Colyer et al., 1998) range from 30-50% for hays, 60-70% for grass, 60% for dehydrated alfalfa to 70-80% for grains and cakes (Tisserand and Martin-Rosset, 1996). For hays, true N digestibility does not seem to be affected by cell wall content (Figure 2). For concentrates, there is a relevant relationship between the true N digestibility in the total tract calculated by INRA (INRA, 1984-1990) and the true N digestibility measured by INRA with the MNBT method in the small intestine of fistulated horses (Figure 3).

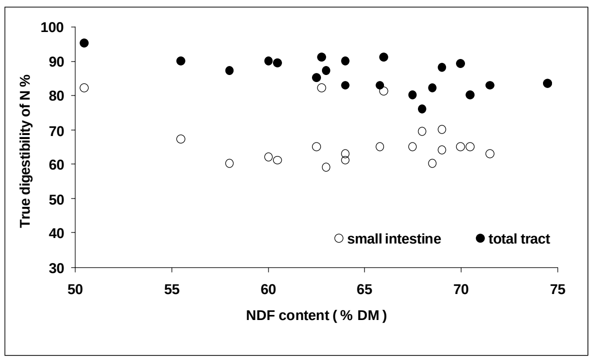


Figure 2. Effect of Neutral Detergent Fiber (NDF) content on the true digestibility of nitrogen of 20 different hays measured in the small intestine by MNBT methods (from Macheboeuf et al., 1995 and Martin-Rosset et al., 2000).

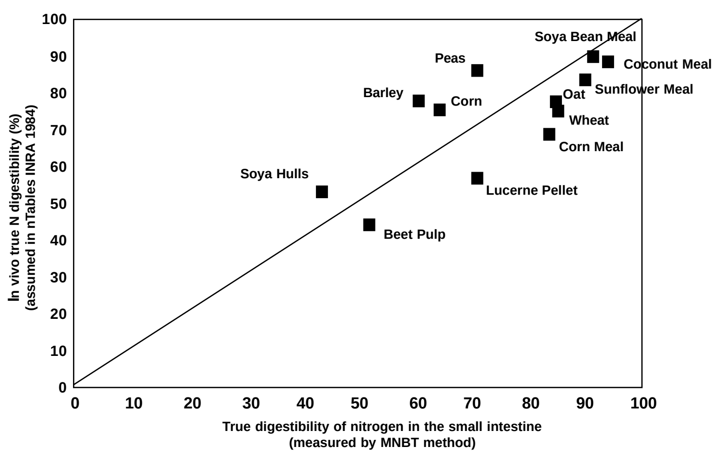


Figure 3. Relation between nitrogen true digestibility of 12 concentrates in the total tract assumed in INRA tables (1984) and true digestibility of nitrogen measured by MNBT method (Macheboeuf et al., 1996) in the small intestine by INRA (1994-1996) (Martin-Rosset et al., 2000).

The true digestion coefficients of feed N in the large intestine measured in slaughtered equines, in ileal-fistulated ponies (Jarrige and Tisserand, 1984; Martin-Rosset et al., 1994; Cuddeford, 1997; Glade, 1983-1984; Potter et al., 1992-1995) and with mobile nylon bag technique at INRA (Cordelet, 1990; Macheboeuf, 1995-1996) range between 75-90% for forages and concentrates (cereals and cakes). Finally, fecal nitrogen is composed of indigestible feed nitrogen mostly bound to fiber (so-called acid detergent insoluble nitrogen or ADIN), endogenous nitrogen (3 g N/kg DMI) and microbial protein nitrogen (50-60% of total N in feces) (Meyer et al., 1993). The amount of soluble N is rather low (Nicoletti et al., 1980). Feed proteins (and endogenous proteins) are degraded partially in the large intestine as amino acids (AA), peptides, and ammonia and resynthesized to microbial protein according to available energy and the type of nitrogen (Robinson and Slade, 1974 ; Meyer, 1983 ; Jarrige and Tisserand, 1984 ; Martin-Rosset et al., 1994). Microbial protein thereafter provides free AA and ammonia. It was assumed by INRA that no more than 10-30% of nitrogen in the large intestine would be absorbed as AA and peptides, which is in accordance with what it is known in pigs and ruminants. These assumptions are drawn from the work conducted in equines on the efficiency of AA absorption either in vivo with isotopic techniques and labelled bacteria with N_{15}, C_{14}, S_{35} (Slade et al., 1971; Goodbee and Slade, 1972; Wysocki and Baker, 1975; McMeniman et al., 1987; Schmitz et al., 1990), the technique of infusion of homoarginine into the cecum or overdosing different AA infused into the colon (Tisserand et al., 1996) and in vitro with cecal (Freeman et al., 1989 and 1991) or with colon mucosa (Bochröder et al., 1994).

From the above considerations, the protein value of feeds for the horse is referred to as the sum of feed and microbial AA absorbed in the small and large intestines, respectively, and expressed in Horse Digestible Crude Protein (Matières Azotées Digestibles Cheval or MADC in French).

The attempt to evaluate amounts of absorbable AA in the whole digestive tract on the basis of true digestibility measured in the small intestine and in the large intestine points out that digestible crude protein (DCP) overestimates the value of forage expressed in MADC by 10 to 30% (Table 2). As a result, MADC content of the main group of forages is calculated by reducing their DCP content by:

1) 10% for green forages;
2) 15% for hay and dehydrated forages;
3) 30% for good quality grass silages;

or multiplying DCP content respectively by a factor K which is 0.90, 0.85, 0.70 for the forages listed previously (Table 4). There is no limitation for concentrate. As a result K= 1.0.

Table 2. Assessment of the amount of absorbable intestinal amino acids (expressed in AIAA) provided by some feedstuffs. Comparison between forages and concentrates (in g/kg DM)[a].

	Crude protein		Small intestine			Large intestine				Total tract	
Feedstuffs	Total g	Non-aminated g	Entry g	true digestibility	AIAA g	Entry g (1)	true digestibility	AIAA % (2)	AIAA g	MADC g	DCP g
Rich	180	9	171	0.85	145	26	0.90	10	2	147	148
concentrates								30	7	152	
(crude fiber 8%)				0.75	128	43		10	4	132	
								30	12	140	
Green grass	180	18	162	0.70	113	49	0.80	10	4	117	128
at early								30	12	125	
grazing stage				0.60	97	65		10	5	102	
								30	16	113	
Barley-corn	110	5	105	0.85	89	16	0.90	10	1	90	90
mixture								30	4	93	
				0.75	79	26		10	2	81	
								30	7	86	
Grass-hay	110	11	99	0.50	50	49	0.75	10	4	54	65
(at heading)								30	11	61	
				0.40	40	59		10	4	44	
								30	13	53	
Grass silage	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	

[a] Jarrige and Tisserand, 1984
(1) Entry : in grams of aminated nitrogen provided by feeds
(2) Percentage of alimentary proteins absorbed as amino acids and peptides ; AIAA: absorbable intestinal amino acid

This type of expression allows the comparison of the feeds and their substitution on the basis of their AA supply. The MADC content per kg DM of cereal straw is 0 but ranges from 30 to 80 g/kg for grass hays and from 80 to 100 g/kg for alfalfa hays according to stage and harvest conditions. The MADC content averages 79 g/kg DM in maize grain, 92 g/kg DM in barley, 98 g/kg DM in oats and reaches 496 g/kg DM in soyabean meal. The MADC supplied by the feeds of a ration are additive.

Example: A diet containing 8 kg of grass hay (50 g MADC/kg fresh material) and 2 kg of barley (80 g MADC/kg fresh material) supplies 400 g MADC + 160 g MADC (respectively) = 560 g MADC.

In a few situations, the expression has to be refined by essential AA content for specific requirements (for example, lysine for growth) (NRC, 1989); threonine is questioned (Hintz and Cymbaluk, 1994).

Tables of the Nutritive Value of Feeds

The chemical composition, the energy value (NE) and protein value (MADC) of feeds were computed in a new set of tables by INRA in 1984 and 1990. The tables include 150 feeds, including fresh forages, silages, dried forages, roots, tubers, cereals, seeds and their byproducts.

In addition, sets of equations were given in the introduction of the tables to predict energy and protein values of feeds from their chemical composition provided by laboratory analysis.

The NE value of feeds (expressed in Mcal or UFC) can be predicted accurately either from tabulated values stated by INRA (1984-1990) or from laboratory analysis (Tables 3a and 3b). The accuracy can be improved by using the digestible organic matter (DOM) content of feeds which can be estimated by the enzymatic (pepsine cellulase) method (Martin-Rosset et al., 1996b) or the near infrared spectrophotometric method (Andrieu et al., 1995 and 1996). The gas production method might be promising using fecal mocula (Lowman et al., 1997; Macheboeuf and Jestin, 1998), but the method is heavier than enzymatic or NIRS methods and less reliable as pointed out by recent studies (Macheboeuf et al., 1998a and 1998b; Cuddeford, 1999).

The nitrogen value of feeds can be predicted in the MADC system from the chemical composition of feeds (namely % CP) by using the appropriate relationships (Table 4) based on in vivo (total and/or partial) digestibility determination in the horse (Martin-Rosset et al., 1984; Macheboeuf, 1995-1996).

As a result, the nutritive value of feeds can be predicted in two ways :

1) either directly by the tables when the information concerning the feeds is available
2) or indirectly by using the appropriate equations (Tables 3 and 4) when laboratory analyses are provided using the most updated methods.

Table 3a. Prediction equations of the UFC value of feeds for horses from chemical composition and digestible organic matter or digestible energy content (Martin-Rosset et al., 1994 and 1996).

	RSD	R^2
2.a - Forages (n = 47)		
N° 2.1 UFC = 0.825 -1.090 CF + 0.555 CP	0.043	0.832
N°2.2 UFC=0.568-0.650CF +0.687CP+1.804CC	0.031	0.922
N° 2.3 UFC = - 0.124 + 0.254 CC + 1.330 DOM	0.012	0.988
N°2.4 UFC=-0.056 +0.562 CC +0.0619 DE	0.007	0.996
2.b - Concentrates; Raw materials (n = 51)		
N ° 2.5 UFC = 0.815 - 0.947 CF + 0.0345 CP + 0.582 CC	0.060	0.931
N° 2.6 UFC = 0.131- 0.628 CF - 0.282 CP + 1.340 DOM	0.041	0.967
N° 2.7 UFC = - 0.730 - 0.722 CP + 0.572 OM + 0.0941 DE	0.033	0.979
N°2.8 UFC=-0.134+0.274CF-0.362CP+0.316CC+0.0755DE	0.017	0.995
2.c - Compound feeds		
N° 2.9 UFCo =1.326 -1.937 CFo - 0.135 Cpo	0.060	0.956
N° 2.10 UFCo =1.333 -1.684 ADFo - 0.096 Cpo	0.060	0.958
N° 2.11 UFCo =1.173 -1.605 CFo + 0.051 CPo + 0.215 STAo	0.043	0.976
N° 2.12 UFCo =1.181 -1.397 ADFo + 0.082 CPo + 0.214 STAo	0.040	0.978
N° 2.13 UFCo =1.219 - 0.852 ADFo - 0.287 NDFo - 0.857 Llo + 0.034 CPo + 0.207 STAo	0.031	0.988

Abbreviations and units

UFC : horse feed unit (per kg DM) ;
UFCo = horse feed unit (per kg OM)
DM: dry matter ;
OM: organic matter;
CF: crude fiber;
CP: crude protein;
CC: cytoplasmic carbohydrates
(water soluble carbohydrates + starch);
ADF: acid detergent fiber;
NDF: neutral detergent fiber
CFo, Cpo and others with ‘o’ designation :
expressed in kg /kg organic matter.
DOM: digestible organic matter (kg/kg DM)
DE: digestible energy (MJ/kg DM)

(kg per kg dry matter)

Table 3b. Average content in water-soluble carbohydrates of forages (% of dry matter) (INRA, 1988).

	WSC	Starch		WSC	Starch
Green forages			**Roots, tubers and**		
Ryegrass			**byproducts**		
Seeding year	3-10		Fodder beet	62	
First growth, leafy	10-15		Sugar beet molasses	62	
stem elongation	10-20		Sugar beet pulp, dried	7	
heading	10-20		Cassava, pellets	3	70
flowering	10-15		Cassava, roots	5	77
Stemmy regrowth	10-15		Potato pulp, dried	1	35
Leafy regrowth	5-10		Sugar beet, molasses		
			Residues	9	
Other grasses			Jerusalem artichoke		63
Seeding year	3-8				
First growth	5-10		Potato		60-65
Regrowth	4-8		Turnip	40	
Lucerne and red clover		Traces	**Cereals**		
First growth, early bud	6-10		Oats	2	44
Late flowering	3-5		Wheat	2	67
2nd and 3rd growth	3-6		Maize	2	72
			Barley	3	59
			Rye	3	62
			Sorghum	1	70
			Rice, paddy	2	70
			Rice, polished	1	85
			Triticale	5	62
White clover	3-4				
			Cereal byproducts		
Maize (whole plant)			Wheat byproducts		
Milk stage (25% DM)	18	16	Low-grade feed flour	5	60
Dough stage (28% DM)	14	24	Feed meal (CF < 6 %)	5	40
Flint stage (33% DM)	10	30	Middlings (CF > 6 %)	5	27
Kale	20-30		Bran	5	22
			Coarse bran	5	17
Conserved forages			Maize byproducts		
Hay, first cut			Gluten feed	3	28
Natural grassland	4-8		Gluten meal	16	
Ryegrass	8-15		Solubles		9
Other grasses	3-8		Bran	6	27
Legumes	2-4		Germ meal	1	25
Hay, regrowth	3-5		Barley byproducts		
Grass silage			Brewers' grain, dried	5	7
Without additives	0-2		Malt sprouts	13	9
With additives			Rice byproducts		
Ryegrass	2-6		Broken rice	2	77
Other grasses	1-2		Low-grade flour	6	23
Maize silage					
Milk stage (25% DM)		20			
Dough stage (30% DM)		28			
Flint stage (35% DM)		34			

(WSC: water-soluble carbohydrates)

Table 4. Relationships between DCP content (g/kg DM) and CP content (g/kg DM) in forages[1].

	n	Relationships	RSD	R
Fresh forages				
Natural grassland, grasses and legumes	14	DCP = - 27.33 + 0.8614 CP	± 7.7	0.967
		DCP = - 74.52 + 0.9568 CP + 0.1167 CF	± 6.3	0.980
Hays				
Natural grassland grasses	47	DCP = - 25.96 + 0.8357 CP	± 7.1	0.968
Legumes	25	DCP = - 29.95 + 0.8673 CP	± 9.2	0.933
All forages	72	DCP = - 27.57 + 0.8441 CP	± 8.6	0.964

[1] Martin-Rosset et al., 1984a and 1994

Calculation of MADC value of feedstuffs with INRA system (INRA, 1984-1990)

MADC = DCP x k

k = 1 for concentrates
k = 0.90 for green forages
k = 0.85 for hays and dehydrated forages
k = 0.80 for straws and their byproducts with high lignin content
k = 0.70 for good grass silages

Requirements and Recommended Allowances

Definitions and Methods for Determination

In France, nutrient requirements and allowances are clearly distinguished. The requirements stand for physiological expenditure of horses for maintenance, pregnancy, lactation, growth and exercise. The requirements are covered by the nutrients of the ration and by the body reserves when the amount of nutrients supplied is inadequate. The nutrient allowances represent the amount of the nutrients provided by the ration. A recommended allowance is the amount of nutrients which should be supplied to horses to achieve a desirable level of performance allowed by their potential. The animals are assumed to be in good health, well managed and housed during the winter period. These should be considered as optimum allowances, which cover at least the requirements.
Exceptions are:

- Draft mares (700 kg BW) where a moderate and controlled used of body reserves is assumed during the winter period to reduce feed costs.
- Growing horses bred for school-riding or hacking where limited growth is assumed during the winter period but a compensatory growth period is expected during the subsequent summer period to achieve an optimum body weight at late breaking.
- Exercising horses where a moderate and controlled used of body reserves is assumed at short term (a few days) during the training period to avoid physiopathologic disorders related to large variation in workload and subsequent daily nutrient intake.

The allowance can be estimated by a factorial method from metabolic data and/or by feeding experiments according to the physiological function. With the factorial method, amount of energy or proteins fixed or exported is divided by the metabolic efficiencies of metabolizable energy or the efficiencies of the digestible crude protein which are specific to the physiological function where these efficiencies are known. With the feeding method, the allowances are determined by long-term feeding trials (and energy or nitrogen balances) conducted with a high number of animals. In these experiments, energy and nitrogen intakes are related to the true performances.

Energy Requirements and Recommended Allowances

In the horse, as in other farm animals, a distinction between maintenance and production requirements has been made, although overall metabolism is influenced by variations in animal expenditures.

Maintenance Requirements

These have been assessed from feeding trials conducted at the end of the last century by Wolff et al., (1880-1898); Grandeau et al., (1888-1904), former feeding standards (Olsson and Rudvere, 1955) and from more recent feedings trials (Breuer, 1968; Stillions and Nelson, 1972; Anderson et al., 1983) and indirect calorimetry trials (Hoffmann et al., 1967; Wooden et al., 1970; Knox et al., 1970) to 140 kcal DE/kg (BW 0.75) or 120 kcal ME/kg (BW 0.75), thus 84 kcal NE/kg (BW 0.75) or 0.038 UFC/kg (BW 0.75) (Vermorel, Jarrige and Martin-Rosset, 1984). These requirements were checked with feeding and calorimetry trials in horses of light breeds (Martin-Rosset and Vermorel, 1991). The daily NE requirements reach 8.80 Mcal and 11.44 Mcal for geldings weighing 500 and 700 kg, respectively. The maintenance requirements are increased by 10 to 20% or not according to the breed (Potter et al., 1987; Vermorel, Martin-Rosset, 1997) or for stallions (Axelsson, 1949; Brody, 1945; Nadal'Jack, 1961; Kossila et al., 1972; Anderson et al., 1983); working horses are increased by 5 to 15% to take into account the rise of the overall energy metabolism (Kellner, 1909) and the importance of spontaneous activities related to temper in exercising horses.

Work Requirements

When a horse moves, the energy expenditure exceeds the maintenance requirements. This additional expenditure results from the work done by the skeletal muscles, the increased work done by the respiratory, cardiovascular and other organs, and the increased tone of all the other muscles. The increase in oxygen consumption is the best measurement of increased energy expenditure. It was first measured in laboratory conditions in horses walking on a treadmill (Zuntz and Hagemann, 1898; Hornicke et al., 1974; Person, 1983; Pagan et al., 1987) and later in more natural conditions, with increasingly elaborate mobile equipment, in horses pulling loads (Brody, 1945), harnessed to a sulky (Karlsen and Nadal'Jack, 1964) and finally saddled (Hornicke et al., 1974; Hornicke et al., 1983; Meixner et al., 1981; Pagan and Hintz, 1986b).

The oxygen consumption, which is about 3 ml/min/kg live weight at rest, increases linearly with speeds up to a gallop (550 m/min) for 560 kg saddle horses with riders (Meixner et al., 1981). At the highest speeds studied, 600 to 700 m/min, the oxygen consumption is 100 ml/min/kg live weight. In well-trained horses, the maximum consumption may reach 125 to 140 ml/min/kg live weight. At this peak level, anaerobic metabolism predominates. The oxygen consumption remains high after the effort ceases and returns only gradually to its rest level. This additional requirement, which is a measure of the oxygen debt, is partly used to metabolize the lactate accumulated during the effort (oxidation and synthesis of glycogen).

Table 5. Variations of energy expenditure with velocity in the horse: unit energy cost (INRA, 1984) [(1)].

Situation	Energy expendinture		
	Velocity (m/mn)	(Kcal/mn)	Times of maintenance (maintenance = 1)
Waiting without rider	0	11.5	1.1
Waiting with rider	0	12	1.2
Walk	110	50	2.5
Slow trot	200	110	10
Normal trot	300	160	15
Fast trot (*)	500	350	35
Normal gallop	350	210	20
Fast gallop (*)	600	420	40
Maximum velocity (*)		600	60

(1) The energy expenditures were calculated from the oxygen consumption (and oxygen debt) by Meixner, Hornicke and Ehrlein (1981) in horses of 560 kg body weight carrying a load of 100 kg (rider + tack + apparatus). For the walk, energy expenditure was calculated from various data (Brody, 1945; Hoffmann et al., 1967; Nadal'Jak, 1961; Zuntz and Hagemann, 1898).

(*) Value calculated from the maximum oxygen consumption of horses estimated by Vermorel, Jarrige and Martin-Rosset (1984) and the oxygen debt.

From all these data, INRA has calculated the **energy costs of locomotion per meter/minute** (m/min) when the oxygen debt is included, at standard velocity for different gaits in a horse weighing 560 kg and riding with a 100 kg load: rider + saddlery (e.g. the unit energy costs) (Table 5). The energy expenditure was calculated from the measurement of oxygen consumption multiplied by the thermal equivalent (kcal/l) corresponding to the RQ (respiratory quotient) calculated at each measurement point (Brody, 1945).

Because the energetic efficiency falls as the velocity increases, energy expenditure rises exponentially (Zuntz and Hageman, 1898; Brody, 1945; Nadal'Jak, 1961; Hoffman et al., 1967 ; Vogelsang, 1981; Pagan and Hintz, 1986b; Martin-Rosset, 1993). Relative to rest, the energy expenditure of a 560 kg horse (carrying a 100 kg load comprising rider, saddle and measuring equipment) is 11.5 cal/mn. The energy expenditure of the horse during locomotion, calculated using all the available data (Hornicke et al., 1983; Karlsen and Nadal'Jak, 1964; Hoffman et al., 1967; Meixner et al., 1981; Thomas and Fregin, 1981; Pagan and Hintz, 1986b), is increased tenfold at a slow trot (200 m/min), 40-fold at a fast gallop (600 m/min) and about 60-fold at top velocity (Table 5).

When the velocity is a constant walking pace (80 to 100 m/min) the energy expenditure of locomotion expressed in kcal per live weight per horizontal meter traveled is roughly constant, 0.55 to 0.31 kcal/kg/m (Hoffman et al., 1967; Zuntz and Hagemann, 1898). The energy expenditure associated with the effort is proportional to the distance up to 24 km. It represents an increase in the energy expenditure of the horse at rest of 7% per hour walking (Hoffman et al., 1967). It is proportional to the duration of the work. However the energy cost of horizontal locomotion is multiplied by 2.5 on a 10% slope, and by 15 when the horse clears an obstacle measuring 1 m.

But, the **total daily energy expenditure for work,** which is additional to the maintenance expenditure of the animal at rest, results from four variables :

1) The duration of the work, which is easy to measure and indeed is standardized to some extent in stables and riding schools.
2) The intensity of the work. The energy expended doing one hour of work is extremely wide ranging (unlike that required to produce 1 kg of milk or even 1 kg of growth).
3) The ancillary effects of the work, or prolongation of the expenditure incurred reverting to the resting state (e.g. oxygen debt), and demand before start of work (e.g., response to stress), such as a characteristic increase in heart rate when the horse is saddled (Thomas and Fregin, 1981).
4) A general elevation of the level of metabolism, likely during intensive work (e.g. training for competition).

We need to evaluate an order of magnitude for **the energy cost in NE of a standardized hour of work** in the main conditions in which horses are used (Figure 4). Two evaluation methods can be envisaged, one factorial (analytical method), the other the global method (feeding experiments).

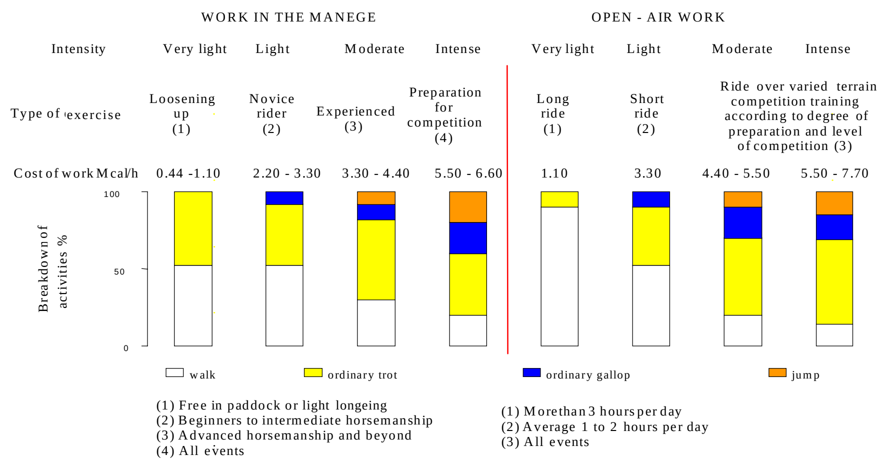


Figure 4. Approximate evaluation of energy cost per hour of work done by a sport horse according to the nature and duration of the work, additional to daily maintenance requirements (from INRA, 1984 and 1990; Martin-Rosset et al., 1994)

The analytical method breaks down the hour of work into periods of different intensities, each assigned a corresponding unit cost, as shown in Table 5. Even if the two components (1) and (2) are correctly evaluated, which is very difficult, uncertainty remains concerning the weighting to be given to the two others (3) and (4), possible interactions between different periods, and metabolizable energy efficiencies for activities of different intensities.

The global method comes down to measuring the quantity of energy required for adult horses in different situations to maintain constant body weight and body condition. This is the most satisfactory method both in practice and from a physiological standpoint, because it takes into account all four variables. However, it is applicable only in certain well-defined situations, and requires determination of nutritive value of feeds, weighing food intake and horses, and measuring variations in body reserves which is seldom done to state an energy balance.

INRA has used the analytical method to calculate **the cost of an hour of work** from its components (Figure 4) and the unit cost of each (Table 5). Also taken into account were the ancillary effects of anticipation and remanence. This loading, which ranges from 10 to 20%, can only be very approximate using current knowledge. To test its reliability, it was applied during long term experiments to horses at the National Riding School at Saumur in France (n = 80 horses used for high level riding instruction and for competition: B and C jumping classes and two and three star three-day events) and at the Animal Technology Teaching Centre at Rambouillet near Paris, France (n = 24 horses used for medium level riding instruction and for competition such as C and D jumping classes and one and two star three-days events). Energy requirements were calculated from the weights of horse and the work measured on the track (duration, velocity), the energy values of the rations having been measured (digestibility and indirect calorimetry according to Vermorel, Martin-Rosset, 1997b) and allowing for variations in live weight and body reserves (INRA, 1990-1997; Martin-Rosset and Vermorel, 1991; and Martin-Rosset et al., unpublished). The feed allowances were the same order of magnitude as the requirements calculated by the analytical method, allowing for ancillary effects. This encouraging result shows that the basis of the calculation used is satisfactory, and the energy allowances recommended in 1984 and updated in 1990 (Figure 4) are reasonable. These values are orders of magnitude which will need to be refined in the future, especially for intense effort, when more is known about the effects of mettle and age, the horse's ability to adapt to training and the environment, and the rider's proficiency.

The energy requirements for work are additional to those for maintenance. For practical reasons, and in particular to forestall rationing errors, recommended total daily energy allowances tables (maintenance plus work) have been drawn up for the situations most often encountered by sport and leisure horses of different sizes (Table 6a). These tables are used directly to calculate rations.

Table 6a. Recommended daily energy allowances (Mcal) for exercising sport and leisure horses (adapted from INRA, 1990).

Use	Live weight [1] kg			
	450	500	550	600
	NE (Mcal) per day			
Maintenance: Horse at rest[5]	8.99	9.73	10.47	1.20
Work				
Very light [2][4]	11.32	11.88	12.44	13.2
Light [2][4]	14.52	15.18	15.84	16.50
Moderate[2][4]	16.72	17.38	18.04	18.70
Intense [3]	15.35	15.95	16.55	17.16

NE : Net energy (Mcal) adapted from INRA energy requirement evaluation system (INRA, 1984 ; Martin-Rosset et al., 1994 ; Vermorel and Martin-Rosset, 1997)

(1) This allowance is for geldings and dry mares. For stallions, add 0.88 Mcal (1.10 Mcal for stallions of 550 to 600 kg)

(2) Horse assumed to work 2 h per day (average observed in horse training facilities)

(3) Horse assumed to work 1 h per day

(4) For short rides out, very light work is considered to be 1 h out and light work 2 h out. For long rides, light work is 2-4 h out and moderate work longer than 4 h

(5) Recommended allowance might be increased in resting horse from 5 to 15% depending on breed and intensity of work (INRA, 1984)

Table 6b. Recommended daily energy (Mcal) and nitrogen (MADC) allowances for exercising sport and leisure horses of light breed (500 kg mature live weight[1]) (INRA).

Use	Daily allowances						Daily Feed* (kg DM**)
	NE (Mcal)	MDAC (g)	Ca (g)	P (g)	MG (g)	Na (g)	
Maintenance:							
Horse at rest	9.73	295	25	15	7	12	7.0-8.5
Work:							
Very light [2] [4]	11.88	370	28	16	8	22	8.95-9.5
Light [2] [4]	15.18	470	30	18	9	37	9.5-11.5
Moderate [2] [4]	17.38	540	35	19	10	47	10.5-13.5
Intense [3]	15.95	490	35	19	10	40	10.0-12.0

* The lower values are used with high proportion of concentrate in the diet and the higher with hay-based diet.

** DM: dry matter.

(1) These recommendations are suggested for geldings and mares. 0.88 Mcal NE and 30 g MADC are added daily for stallions.

(2) We considered two hours of daily work (mean observed in riding school).

(3) We considered one hour of daily work.

(4) For short outside riding, very light and light work intensities are considered for one and two hours of exercise, respectively. For medium (2 to 4 hours) and long (> 4 hours) outside riding, light and moderate work intensities are considered.

For load pulling in draft horses, the total energy expense is the sum of energy expenses of locomotion and for load pulling. Pulling work is the result of the developed strength (F in kg) by the distance (d in m) expressed in kilogrameters. The strength of pulling the load and the resulting work during a given period decreases 60% when the velocity increases by 70 to 300 m/mn as measured by Gouin (1932) with half cold-blood horses (500 kg). The energy expenses of the horse rise linearly with the developed power (F x Velocity = kgm/s) and the length of work (Brody, 1945). For cold-blood (half-bred or draft horses), we have preferred to borrow energy requirements for work from former standards (Jespersen, 1949) by Olsson and Ruudvere (1955) because they were set up from feeding trials and practical observations, which were more reliable than assessments based on oxygen consumption as measured by Brody (1945) and Nadal'Jak (1961) on a very small numbers of horses. The additional energy requirements per hour are 0.77 Mcal for light, 1.23 Mcal for medium, 1.65 Mcal for hard and 2.38 Mcal for very hard work.

Pregnancy and Lactation Requirements

These are above maintenance and have been estimated by a factorial method (Martin-Rosset and Doreau, 1984) and revised by the same group (INRA, 1990). The increase in energy content of the fetus was calculated from the data of Dusek (1966), Den Engelsen (1966) and Meyer and Alshwede (1976) to estimate the amount of energy retained by the fetus (Table 7). The efficiency of energy utilization for pregnancy was estimated to be 25% (mean between those in cows and in sows because of the lack of measurements in mares). The amount of energy fixed in the conceptus (fetus, adnexa and placenta) and udder, calculated by multiplying energy content of fetus by 1.20 to take into account the energy fixed in the fetal adnexa, uterus and udder (Martin-Rosset and Doreau, 1984), increases daily from 152 kcal to 467 kcal/100 kg BW/day between the 8th and the 11th month of pregnancy.

Table 7. Weight gain and composition of the fetus*.

Months	Weight gain in % birth weight(1)	Gross energy Mcal/kg(2)	Protein content (%)(2)
8th	19	1.000	11.5
9th		1.100	13.0
10th	30	1.180	15.3
11th	31	1.280	17.1

* From Doreau, unpublished and Martin-Rosset et al., 1994
(1) Drawn from Dusek (1966) and Den Engelsen (1966)
(2) Drawn from Meyer and Ahlswede (1976)

In lactation the amount of energy exported as milk was calculated thanks to better estimates of milk production and energy content (Table 8). Efficiency of energy utilization for milk production was estimated to be 65% from values obtained in the cow and the sow. The energy requirement for milk production is 682 kcal, 594 kcal and 572 kcal/kg for the first month, the second and third months and over the fourth month of lactation, respectively.

Table 8. Milk yield and composition.

Months	Milk yield	Milk composition	
	(kg/100 kg LW)(1)	Energy Mcal/kg(2)	Protein content (g/kg)(2)
1st	3.0	0.575	24
2nd	2.5	0.500	24
3rd	2.5	0.500	24
4th	2.0	0.475	21

(1) Doreau and Boulot (1989)
(2) Doreau et al. (1988)
In the first edition of the INRA recommendation (1984), the requirements were calculated with the available data (Martin-Rosset and Doreau, 1984), but the knowledge has increased a great deal since then.

As a result, the daily requirement for pregnancy (late pregnancy, 8th-11th months) and milk production (early lactation, 0-3 months) is 0.1-0.3 times and 0.9-0.6 times the maintenance requirements, respectively. However, the recommended energy allowances were estimated on the bases of many feeding trials carried out with mares of light or heavy breeds fed different diets, taking into account the possibility of body reserve utilization (Sutton et al., 1977; Henneke et al., 1981a and 1981b; Banach and Evans, 1981; Martin-Rosset and Doreau, 1984). Two levels of energy allowances, high level (HL) or low level (LL), were suggested according to the breed (heavy vs. light) and body condition score (Table 9).

Table 9. Feeding standards for mares and recommended nutrient allowances. Mare of light breeding (500 kg mature live weight) (INRA, 1990)*.

Physiological State	Daily Allowances							
	NE (Mcal/day)		MADC	Ca	P	Mg	Na	Daily feed(3)
	Low level(2)	High(g) level(1)	(g)	(g)	(g)	(g)	(g)	(kg DM)**
Dry mare or early pregnant mare	8.36	10.12	295	25	1	7	12	6.0-8.5
Pregnant mare								
8th & 9th months	9.02	11.00	340	29	18	7	12	6.5-9.0
10th month	10.34	12.54	460	38	26	7	12	7.0-10.5
11th month	10.56	12.76	485	39	28	7	12	7.5-11.0
Lactating mare								
1st month	19.58	23.54	950	61	55	10	15	12.0-15.0
2nd and 3rd month	16.72	20.24	800	47	40	9	14	10.0-15.0
4th month to weaning	13.42	16.50	660	39	32	8	13	8.0-12.5

* Live weight 24 hours after foaling;
** DM: dry matter
(1) For mares whose offspring are used in competition with the exception of the mares that are fat (body condition score (4) (INRA, 1990). Other mares (body condition score (2.5) and mares wintered outdoors or bred at three years old.
(2) Other cases.
(3) The lower values are used with proportion of concentrate in the diet and higher with hay-based diet values.

In **heavy mares**, energy allowances account for:

(1) 100 % (HL) or 80 % (LL) of total energy requirement in dry mares, pregnancy or late lactation (period 1)
(2) 110 % (HL) or 90 % (LL) of total energy requirement in early lactation (period 2)

These levels of energy allowances were suggested for two reasons :

(1) a moderate undernutrition in late pregnancy has no significant effect on the body weight and health of the foal at birth and its growth if the body condition score is good in early lactation.
(2) the effects of undernutrition in early lactation on the reproductive capacity of the mare are not well known. In light mares, energy allowances account for:
  (1) 110 % (HL) or 90 % (LL) in period 1
  (2) 120 % (HL) or 110 % (LL) in period 2

The suggested levels are higher for mares of light breeds to take into account the requirements of foals devoted to competition (bloodstock).

Growth Energy Requirements

These have been evaluated from feeding trials (Agabriel et al., 1984; Bigot et al., 1987; Micol and Martin-Rosset, 1995) in which NE intake, weight and weight gain of young horses were precisely measured, for three reasons.

(1) The energy requirement for maintenance (kg BW 0.75) varies with breed and growth rate. The variations in maintenance requirements due to breed are known only in the adult. Maintenance requirements account for 60-90% of total energy requirement of the growing horse.
(2) The amount of fixed energy per kg weight gain computed from the chemical composition of tissues was determined only in heavy breeds (Martin-Rosset et al., 1983).
(3) The efficiency of metabolizable energy utilization for growth is not known yet.

Energy allowances were computed according to body weight (BW) and weight gain (G) of young horses using a relationship established from the results of feeding trials carried out at INRA, and according to the following model drawn from the growing bull (Geay et al., 1978; Robelin, 1979) :

$$\text{NE/kg BW 0.75/day} = a + bG^{1.4}$$

a = coefficient of maintenance requirement
G = average daily gain; kg/day

The validity of the model and namely of the exponent '1.4' was checked in horses from the results of slaughter experiments in young heavy horses and extended to light breeds (Agabriel et al., 1984) (Table 10).

Table 10. Requirement for growth.

Energy : relationship between daily energy intake and live weight and growth in young horses of *light breeds* UFC/day/kg$W^{0.75}$ = a+b$G^{1.4}$			Protein : relationship between daily protein intake and live weight and growth in young horses of *light breeds* gMADC/day = a$W^{0.75}$ + bG		
Ages (months)	a	b	Ages (months)	a	b
6-12	0.0602	0.0183	6-12	3.5	450
18-24	0.0594	0.0252	18-24	2.8	270
30-36	0.0594	0.0252	30-36	2.8	270

a : coefficient of maintenance
G : average daily gain (kg/day) (Adapted from data of Agabriel et al., 1984 and Martin-Rosset et al., 1994)
UFC = Horse Feed Unit (2200 Mcal Net energy) in INRA energy requirement evaluation system (INRA, 1984 and 1990) *Relationships are different for heavy breeds (Agabriel et al., 1984)*

The relationships for the growing light-breed horse are given in Table 10. For 1 kg of daily gain, total requirements account for 10.78 Mcal at 250 kg BW and 14.08 Mcal at 350 kg BW. The increase deals with the maintenance requirements + 2.42 Mcal (8.36 Mcal at 250 kg BW compared to 10.8 Mcal at 350 kg BW) and with the cost of 1 kg of body gain + 0.88 Mcal (2.42 Mcal at 250 kg BW compared to 3.30 Mcal at 350 kg BW). At the same body weight, 300 kg, maintenance requirement reaches 9.46 Mcal but the cost of 1 kg of body gain increases with the level of growth, + 1.76 Mcal when growth requirement is calculated for 0.5 kg daily gain (1.10 Mcal) and compared with the requirement for 1 kg daily gain (2.86 Mcal). **Two levels of allowances** were suggested according to the goal of production (horses produced for school riding and hacking vs. bloodstock produced for competition) and the growth potential of the young horses (Table11) :

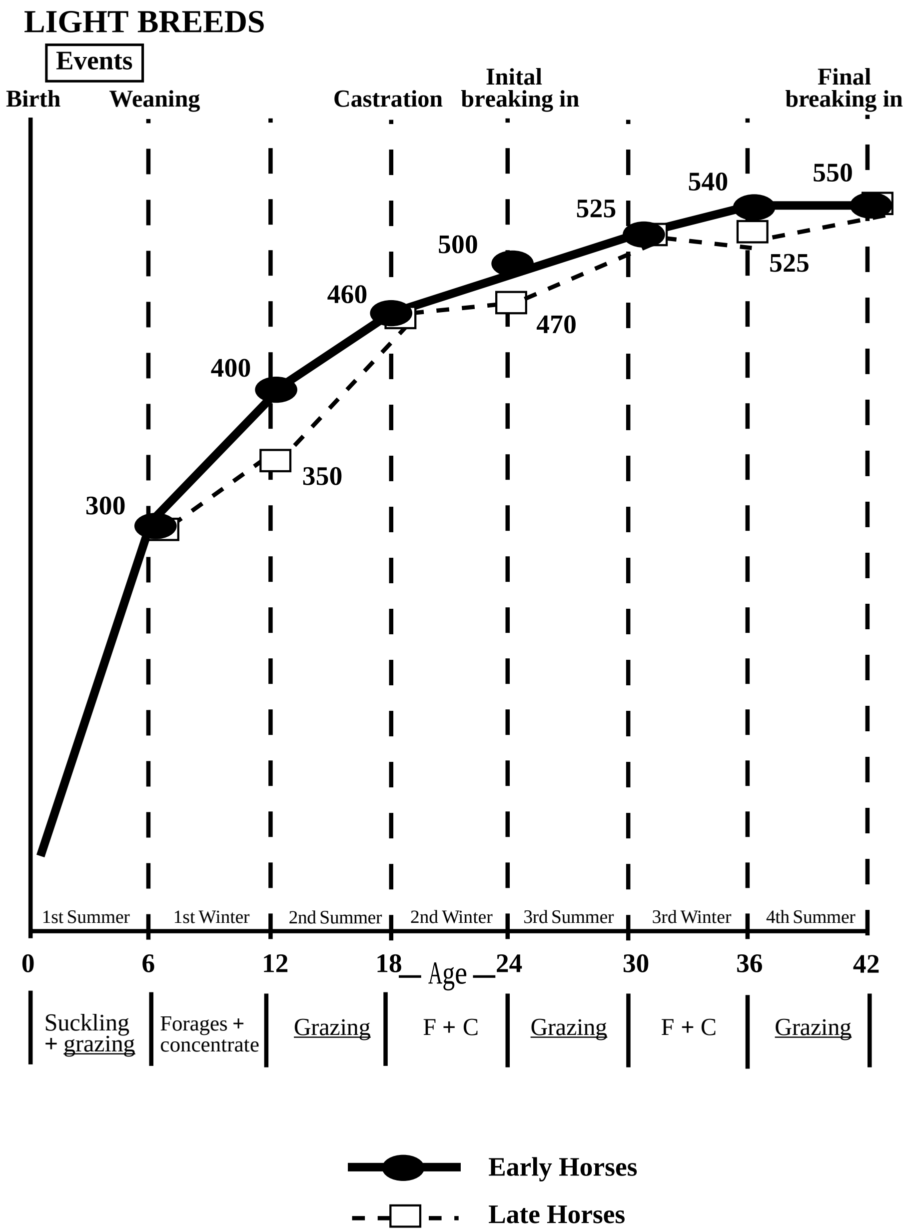
Table 11. Feeding standards for the growing horse. Recommended nutrient allowances for horses of light breeding (500 kg mature body weight) (INRA, 1990).

Age (months)	Mean body weight during the period (kg)	Growth		Daily allowances						Daily Feed * (kg/DM)**
		Level	Daily gain (g/d)	NE (Mcal)	MADC (g)	Ca (g)	P (g)	Mg (g)	Na (g)	
8 -12	320	Optimal	700-800	12.10	590	39	22	10	12	5.5-8.0
	280	Moderate	400-500	9.90	440	28	16	9	9	5.0-7.5
20 -24	470	Optimal	400-500	4.96	420	36	20	10	13	7.5-10.0
	440	Moderate	150-200	13.20	330	28	16	9	12	7.0-10.0
	490	Optimal	150-250	14.30	330	30	18	10	12	8.0-11.0
32 -36	470	Moderate	0-100	13.20	260	25	15	8	12	7.5-10.0

* The lower values are used with high proportion of concentrates in the diet and the higher values with hay-based diet.
** DM: dry matter

(1) optimal level for high growth (close to genetic potential) in young horses bred for competition:
(2) moderate level for limited growth in young horses bred for hacking but having compensatory growth on pasture (Figure 5).

Figure 5. Growth curve and management of young sport horses (Selle Français or Anglo-Arab) established from INRA long-term feeding experiments (INRA, 1990).



Protein Requirements and Recommended Allowances

On the basis of the nitrogen balance set up by Slade et al., (1970), and Prior et al., (1974), MAINTENANCE REQUIREMENTS have been estimated to be 2.4 g DCP (digestible crude protein)/kg $BW^{0.75}$; expressed in MADC, allowances are 10-15% higher, 2.8 g MADC/kg $BW^{0.75}$ because the DCP content of forages has been reduced by 10 to 20%. Daily allowances reach 295 g and 380 g MADC respectively for horses weighing 500 and 700 kg. Hence, recommendations are very close to those suggested by the NRC (1978) (2.8 DCP/kg BW $^{0.75}$). INRA recommendations cannot be compared to the new requirements suggested in crude protein (CP) by 1989 NRC. The former requirements were compiled by Olsson and Ruudvere (1955). However, they are lower than those calculated with the factorial method (Meyer, 1983) as this author took into account the possibilities of storing proteins.

All the feeding trials, digestion studies and nitrogen balances carried out show that the AA composition of the common diets for adult horses at maintenance is of no importance and that NPN (urea particularly) can be successfully used by the horse if the fermentable energy supply in the large intestine is sufficient.

Work

For work, protein expenses are unknown. They could increase more than energy expenses in relation to intensity and length of work if energy supply is sufficient to prevent body protein mobilization (Kellner, 1909). Thus, there is some reason to relate protein and energy supply for work to protein synthesis where the protein gain is positively related to the protein and energy contents of the diet. **A supply of 60 to 70 g MADC/UFC beyond maintenance requirements** seems satisfactory for the adult horse at work. A greater supply should be necessary for the two-year-old in training to enable increases in muscular mass, in the concentrations of myoglobin and in enzymes responsible for muscular metabolism as well as to prevent anemia. For the human athlete, protein supply should be increased by 20% at the beginning of training and by 100% during intensive training (Willmore and Freund Beau, 1984). There is no evidence to increase the protein or AA supplementation to equine athletes over what it is recommended for human athletes (Lawrence, 1998).

The protein requirements for pregnancy beyond maintenance were calculated by the factorial method (Martin-Rosset and Doreau, 1984). The total amount of daily protein was calculated by dividing the amount of protein fixed in the conceptus (Table 7) by the metabolic efficiency of DCP for that function. It has been stated at 55%, whereas Meyer (1983) and NRC (1978) assumed that it was 50 and 45% respectively. That efficiency is slightly lower than the value for pigs and ruminants (60%). The daily amount of protein fixed in the conceptus (fetus + adnexa + placenta + udder) reaches 5.0 g/100 kg BW and 21 g/100 kg BW between the 8th and 11th months of pregnancy. The recommended allowances given in the INRA table (1984-1990) account for 100% of the requirements (Table 9).

The protein requirements for milk production (above maintenance requirements) were also calculated by the factorial method on the bases of the amount of proteins expended daily in milk (Table 8) and of the metabolic efficiency of DCP estimated to be 55%. This efficiency is close to those suggested by Meyer (1983), 50 to 60%; Broster (1972) suggested true DCP to be 50-55%. The efficiency retained by NRC in 1978 and 1989 (69%) seems too high if we refer to the efficiency measured in ruminants (60% for the DCP). The protein allowances suggested account for 100% of the requirement (Table 9) as the influence of protein deficiency in the mare is not well known (Martin-Rosset and Doreau, 1984; Doreau et al., 1988). The protein allowances per kg of milk are 44 g, 38 g, and 36 g for the 1st month, 2nd and 3rd months, and 4th month of lactation, respectively.

Growth

Protein requirements of growing horses (above maintenance) were calculated from protein retention. The latter can be determined accurately from the composition of empty body weight and weight gain. This was defined on the basis of anatomical composition data on animals slaughtered at different ages (Martin-Rosset et al., 1983) after several feeding trials (Agabriel et al., 1984).

Protein requirements of heavy breeds were estimated by the factorial method because all the feeding trials conducted were designed to define the optimum CP content of the diet or the effect of feed protein quality on the growth of the young horse. The efficiency of MADC stated was 45% as suggested by the NRC (1978). It has been suggested to supply 3.5 g MADC/kg $BW^{0.75}$ for maintenance in the young horse, instead of 2.8 g MADC/kg $BW^{0.75}$ for maintenance in the young horse until one year of age, to take into account the faster turnover of body protein, 25% as measured in other species (Reeds and Harris, 1982).

In light breeds, protein requirements were calculated by using a mathematical model similar to that used for energy (Table 10) as there were enough INRA feeding trials (Agabriel et al., 1984; Bigot et al., 1987) designed to study effect of the CP content of the diet on average daily gain.

Two levels of allowances were suggested in growing horses as for energy considering the goal of production, genetic potential of the animal and the use of compensatory growth on pasture (Table 11).

We have kept allowances suggested by NRC (1978 and 1989) due to the work of Ott et al. (1979, 1981 and 1983) and confirmed by Saastamoïnen et al. (1993) for lysine, the single AA recognized as limiting at this moment even though threonine is questionable (Graham et al., 1993). Lysine is 0.6 % of DM in the diet for the 6-month-old foal and 0.5 % for the yearling and 0.4 % for the two- and three-year-old. Feed protein quality is of less importance as the growth potential decreases with age and the proportion of hay in the diet increases simultaneously.

Tables of recommended allowances (examples tables 6, 9 and 11)

The daily allowances are set up to allow an easy calculation of the rations. These tables are different for light and heavy breeds. There are no tables for ponies as there are not enough available data. The allowances are given for different body weights for light breeds (450, 500, 550, 600 kg) and heavy breeds (700 and 800 kg). In all the situations, the mare, stallion, gelding and the growing and fattening horse are considered in their own physiological situations where applicable and include maintenance, pregnancy, lactation, breeding, growth or fattening, rest and exercise. The allowances are given only for the winter period as it is the only period studied in breeding horses.

The recommended allowances suggested by INRA (1984) were revised by INRA (1990), mainly for mares and growing horses as there were more available scientific data to define requirements and new feeding strategies. They could be slightly revised in 2001 just to take into account the slight variation of NE content of barley, which has moved from 2.200 Mkcal/kg in 1990 to 2.250 Mcal/kg in 1997 (Vermorel and Martin-Rosset, 1997).

The range of amount of daily feed suggested in the tables does not represent the maximum amount of feeds that the horses are able to consume, specifically in growing horses (Bigot et al., 1987) or in mares (Doreau et al., 1988; 1990), but only the amount to cover the nutritient requirements. These amounts of daily feeds are consistent with the ingestibility of the forages measured by INRA, in trials especially designed to study ingestibility (Martin-Rosset and Doreau, 1984; Dulphy and Martin-Rosset, 1997a and 1997b) and because all the intakes were measured in feeding trials in animals fed different diets (Agabriel et al., 1982 and 1984; Bigot et al., 1987; Doreau et al., 1988 and 1990; Martin-Rosset and Doreau, 1984b and1984c; Martin-Rosset et al., 1989). Average value by forage category is proposed by INRA (1990) in its former recommendations published by Martin-Rosset et al. (1994) (Table 12). The recent work of INRA (Dulphy and Martin-Rosset, 1997a and 1997b) supports the idea that there is no relationship between dry matter intake of forages and its chemical components such as CP, CF or NDF, which is consistent with the previous work of Martin-Rosset and Doreau (1984) and Cymbaluk (1990). Therefore, the use of average values proposed previously is still very relevant.

Table 12. Ingestibility of the main forages in growing horses and adult horses (INRA, 1990).

Feedstuffs	Intake [(1)]
	kg DM / 100 kg live weight
Fresh natural meadow	1.8-2.1
Hays : grassland-gramineous	1.7-2.1
hays : legumes	2.1-2.3
Straw	1.2-1.5
Maize silage well preserved	
25 % DM	0.9-1.2
30 % DM	1.2-1.6
Grass silage well preserved (natural meadow)	
25 % DM	1.2-1.5
35 % DM	1.4-1.7

DM: dry matter

[(1)] Maximum intake when the forage is offered alone ad lib. The range represents the average variation between animals according to the quality of the forage offered.

Proportion of concentrates in the diet depends on daily requirement to be covered, then on nutritive value of forages and intake capacity of the different types of equine with regard to their level of performance. Guidelines of concentrate proportions in the diet to meet the requirements are provided to the users in INRA systems (Table 13).

Table 13. Diet composition guidlines (INRA, 1990)

Type of animal	Physiological status Performance goal	Percentages Forages *	Concentrate	Comments **
Light breeds	Pregnancy	50 to 95	5 to 50	Forages G ↗ to VG //
Mares	Lactation			Forages M ↗ to VG//
Stallions	Rest	85-95	5-15	Straw//+Forages M to VG//
	Service	60-70	30-40	Straw//+Forages M to VG//
Growing horses				
	1 year, optimal growth	40-65	35-60	Forages G to VG ↗ or E//
	1 year, moderate growth	65-75	25-35	Forages G and VG ↗
	2 years, optimal growth	75-80	20-25	Forages G to VG ↗ or E//
	2 years, moderate growth	80-85	15-20	Forages M ↗ or G//
	3 years, optimal growth	80-85	15-20	Forages G//
	3 years, moderate growth	85-90	10-15	Straw ↗ + Hay G//
Heavy breeds	1 or 2 years, optimal growth	40-60	40-60	Forages B ↗ to VG//
- growing	1 or 2 years, moderate growth	85-90	10-15	Straw ↗ + hay G//
	10 months, very high growth	30-50	50-70	Forages VG to E ↗
- fattening	12 months, high growth	40-70	30-60	Forages VG to E
Exercising horses				
- light breeds	Rest to intensive	35-95	5-65	Hay G to VG// + Straw//
- heavy breeds		55-95	5-45	Hay M to G// + Straw//

M :Medium quality forages
G :Good quality forages
VG :Very good quality forages
E :Excellent quality forages

* Straw is included in the indicated forages percentages
** Straw is indicated where relevant and its feeding level pointed out
↗ : Forages offered ad libitum
// : Forages offered in restricted amount

These feeding standard tables also include the daily recommended ALLOWANCES FOR MACROMINERALS (Ca, P, Mg, Na) (Tables 6a-9 and 11). The recommendations for TRACE MINERALS and VITAMINS are given alongside in another table (Table 14) where they are expressed in amount per kg dry matter intake (DMI) for the range suggested in the feeding standard tables.

Table 14. Optimum nutrient concentration of horses per kg DM referring to DM intake in the INRA daily recommended allowances tables (INRA, 1990).

	Adults (1)		Mares (2)		Growing horses		
	Rest light work	Medium work mating	End of pregnancy	Early lactation	6-12 months	18-24 months	32-36 months
Energy							
UFC	0.45-0.70	0.50-0.75	0.50-0.70	0.60-0.80	0.65-0.95	0.60-0.90	0.60-0.80
Nitrogen							
MADC (g)	30-50	40-55	45-70	55-90	55-90	40-55	30-40
Macrominerals							
Calcium (g)	3.1	2.9	4.6	4.3	5.5	3.8	3.3
Phosphorus (g)	1.9	1.6	3.2	3.7	3.0	2.2	1.9
Magnesium (g)	0.9	0.9	0.8	0.7	1.6	1.1	1.1
Sodium (g)	2.7	3.2	1.6	1.2	1.8	1.6	1.4
Potassium (g)	4.0	5.0	4.0	3.0	3.0	1.8	1.4
Sulfur (g)	1.5	-	1.5	-	1.5	-	-
Trace elements(3)							
Iron (mg)	80-100	80-100	80-100	80-100	80-100	80-100	80-100
Copper (mg)	10	10	10	10	10	10	10
Zinc (mg)	50	50	50	50	50	50	50
Manganese (mg)	40	40	40	40	40	40	40
Cobalt (mg)	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.2	0.1-0.2	0.1-0.2
Selenium (mg)	0.1-0.2	0.1-0.2	0.1-0.2	0.1-0.2	0.1-0.3	0.1-0.3	0.1-0.3
Iodine (mg)	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.3	0.1-0.2	0.1-0.2	0.1-0.2
Vitamins(4)							
Vitamin A (UI)	3250	3750	4200	3500	3450	3500	3500
Vitamin D (UI)	400	600	600	850	500	600	600
Vitamin E (UI)	8	10	11	7	7	10	10
Thiamine B1 (mg)	2.5	2.5	2.5	2.5	1.7	2.5	2.5
Riboflavin B2 (mg)	4.0	4.0	4.2	4.2	2.8	4.0	4.0
Niacin (mg) pp	12	12	12.5	12.5	8.5	12	12
Pantothenic acid (mg)	5.0	5.0	5.1	5.1	3.3	4.8	4.8
Pyridoxine B6 (mg)	1.3	1.0	1.3	1.2	0.8	1.2	1.2
Choline (mg)	65	60	63	84	42	60	60
Folic acids (mg)	1.3	1.2	1.3	1.2	0.8	1.2	1.2
Cyanocobalamine B12 (µg)	13	12	13	8	8	12	12

(1) The diet nutritive concentration of an intensively exercising horse should be increased.
(2) Mares during the last 3 months of pregnancy and the first 3 months of lactation.
(3) The allowances for traces elements are those suggested by Meyer (1982) in Germany.
(4) The recommended allowances for vitamins are those suggested by Wolter (1975) in France.
Remarks : The single concentrations given for macrominerals, some trace elements and vitamins were calculated for average DM intake.

Consequently, formulating rations for horses is quite easy with the modern INRA systems. NE and MADC values of feeds are additive as there is no forage and concentrate interaction on organic matter digestibility of the ration (Martin-Rosset and Dulphy, 1987) and very limited effect of level of feeding (Martin-Rosset et al., 1990). These systems allow an easy formulation of rations by hand with a graphical method (INRA, 1990) which is necessary to understand, to teach and to advise on the approach to ration formulation. But a ration calculation software package, The Chevalration, developed by teachers (Tavernier and Arslanian) and INRA workers both involved in the preparation of the handbook entitled 'Alimentation des chevaux' (INRA, 1990), is most accurate for formulating well balanced rations.

Comparison of recommended allowances expressed in DE and NE

The aim of any feeding system is to meet the requirement of the animals for type and level of production using available feeds. The nature, chemical composition and nutritive value of these feeds may vary with climatic and economic conditions. Ingestibility and palatability of feed, intake capacity of the animal and substitution rate between forages and concentrates must also be considered.

The differences between the NE and DE systems have been previously pointed out and differences between MADC and DCP systems have been discussed as well. Prediction of feed energy or nitrogen value in NE with regard to MADC and INRA systems has been described previously from a scientific point of view and primarily for the sake of application.

Energy and nitrogen requirements of different types of equines (mares, growing or exercising horses) as well as the energy and nitrogen value of feeds and rations may vary between feeding systems.

As far as the requirements suggested by NRC (1989) and INRA (1984-1990) are concerned and expressed in each system relative to maintenance as 100% bases, the NRC requirements seem to be lower than INRA requirements for energy or nitrogen (Table 15) when comparing the relative difference between the two systems.

As pointed out in the review of Hintz and Cymbaluk (1994), effect of environmental factors might be involved also, and added to the observed discrepancies which are acquainted to coefficients set up in the factorial method to perform the requirements of NRC primarily and of INRA partially. In the case of INRA recommendations, the procedure to implement allowances incorporates the impact of environmental factors because INRA allowances have been set up on feeding experiments designed and performed namely for this purpose or they are based on the requirements established from the factorial approach. Cuddeford (1997) compared NRC and INRA requirements. For energy, comparison takes place on requirements expressed in DE in both NRC and INRA, assuming conversion ratios from NE to DE drawn from INRA feed evaluation systems. For nitrogen, Cuddeford (1997) matched INRA requirement expressed in MADC to NRC requirement expressed in DCP, assuming digestion coefficient of CP drawn from NRC (1978). Conclusions are that NRC requirement would be slightly higher than INRA requirement for energy and for protein namely for growth, and for pregnancy to a lesser extent. But NRC energy requirement for pregnancy and lactation would be similar.

Table 15. Energy or nitrogen requirements (500 kg horse) related to maintenance in DE and CP system (NRC, 1989) and NE and MADC systems (INRA, 1984-1990). Relative difference between the systems.

SYSTEMS / ANIMAL	Energy			Nitrogen		
	NRC	INRA	%NRC/INRA	NRC	INRA	%NRC/INRA
MATURE HORSE						
- Maintenance(1)	**100**	**100**	**100**	**100**	**100**	**100**
- Mare						
• Pregnant						
8th 9th month	111	108	103	122	126	97
10th month	113	123	92	124	170	73
11th month	120	125	95	132	180	73
• Lactating						
1st month	173	232	75	218	352	62
2nd 3rd month	173	200	87	218	296	74
4th month weaning	148	161	92	160	244	66
GROWING HORSE						
• Yearling (12 months)						
Rapid growth	130	130	100	146	227	64
Moderate growth	115	107	107	130	169	76
• Two-year-olds (24 months) (not in training)						
Rapid growth	148	161	92	157	156	100
Moderate training	113	142	80	120	122	98
WORKING HORSE						
Very Light	125	128	98	125	137	91
Light	-	163	-	-	174	-
Moderate	150	187	80	150	200	75
Intense	200	172	116	200	182	110

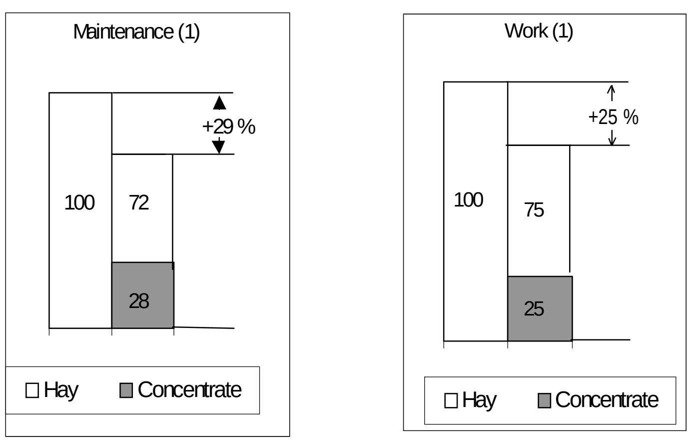
(1)Stricto sensu maintenance requirement in adult horse whatever the systems

Base 100	INRA = 9.3 Mcal NE, 270 g MADC
	NRC = 16.4 Mcal DE, 656 g CP

Concerning the net energy requirements for work and maintenance, Harris (1997) pointed out that INRA requirements cannot be compared with requirements calculated through a partitioning system for the INRA system would assume the same efficiency of feed energy for work as for maintenance. The NE INRA system does not assume that efficiency of feed energy is the same for work and maintenance. The requirements (e.g. allowance in INRA system) have been determined with long-term feeding experiments. Factorial method was only implemented at the beginning of the research to state the scientific basis of the energy requirement variations according to the duration, intensity and ancillary factors.

The INRA system is based on the concept that the NE value of nutrients for both maintenance and work (physical activity) depends on the free energy (ATP) produced by their oxidative catabolism (Vermorel and Martin-Rosset, 1997). This concept was already suggested by Armsby (1917) in his famous handbook entitled 'The Nutrition of Farm Animals.' INRA has taken into account the new figure, that muscular contraction requires ATP as well as the other maintenance energy expenditures.

More than a century ago, German and French workers (Wolff et al., 1888-1895; Grandeau Alekan, 1904) stated that the maintenance DE requirements of horses were much higher with a hay-based diet than with a hay and concentrate diet (Figure 6). On this basis, a NE system for work was established by these workers (Table 16). It compares very well with the NE system for maintenance (Table 16) proposed by INRA. It has been extensively confirmed by other workers to this day.



(1) Requirements in digestible energy

Figure 6 : Relative nutritive value of feeds at maintenance and work (adapted from Wolff et al., 1880-1895 and Grandeau et al., 1888-1904)

Table 16. Relative net energy value of feeds to barley for a horse at work and at maintenance.

	WORK Adapted from Wolff et al., 1888-1895	MAINTENANCE Adapted from INRA, 1984		
	Relative NE	Relative NE	NE (Mcal/kg DM)	UFC (/kg DM)
Maize	117	114	2.90	1.32
Barley	**100**	**100**	**2.55**	**1.16**
Oat	87	87	2.22	1.01
Horsebean	107	94	2.40	1.09
Pea	99	100	2.57	1.17
Lucerne hay	53	54	1.38	0.62
Grass hay	44	47	1.21	0.55

As a result, feeds can be substituted on their NE value for maintenance to cover the work energy expenditure. INRA allowances performed on such assumptions through long-term feeding experiments carried out for that purpose are relevant as pointed out by Harris (1997). This approach for determining energy work requirement through long-term experiments is still the most consistent. No country has available facilities to do otherwise even though INRA keeps in mind that energy requirements and allowances for intense work implemented in various types of high competition races, three-day events, and endurance rides require more refinement as pointed out by Southwood et al. (1993), Lawrence (1994), and Jones and Carlsson (1995).

As nutrient requirements as well as nutritive value of feeds and rations vary among feeding systems, it is essential to evaluate whether total energy and protein requirements of the different types of equines can be met by the same amount of feeds in balanced rations of the various feeding systems, namely NRC vs. INRA.

Frape (1997) compared applications of DE (NRC, 1989) and NE (INRA, 1990) systems to the formulation of simple balanced daily rations based on grass hay, barley grain and extracted soyabean meal for a horse 500 kg at maturity in regard to energy and protein and with feed intakes, kg DM/day provided by NRC (1978). Total dry matter intakes (TDMI) for each type of animal are stated to be the same in the two feeding systems for a type of animal. As a result, the hay to concentrate ratios vary to match energy and protein requirements in each system.

Dry matter intake for forage (DMIF) is lower with the NRC system for all types of equines, with the exception of the exercising horse where it is higher. The discrepancies range between - 9 to - 24% for breeding horses and + 9 to + 19% for exercising equines respectively. The inconsistency of differences between NRC and INRA may partially be due to differences in requirements between NRC and INRA. Descriptions of, and as a result requirements for, high and moderate work are different between the two systems (NRC, 1989 and INRA, 1990; Martin-Rosset et al., 1994). For example, light work in NRC (1989) recommendations corresponds to very light work in INRA 1990 recommendations.

As a result the appropriate procedure to compare the two systems that INRA proposes is as follows. Requirements for each type of equine are provided in each system according to performances level: DE, CP and DMI for NRC (1989) and NE, MADC; DMI for INRA (1990).

Good and poor (in some situations) quality hay-based diets were tested. Forages were supplemented with barley and extracted soybean meal in appropriate proportions to meet the energy and protein requirements of the different types of equines depending on their performance level. The characteristics of the four feeds used are given in Table 17.

Table 17. Chemical composition and nutritive value of feeds.

Feeds	DM	/kg DM							
	g/kg	DE (Mcal)	NE (Mcal)	CF (g)	CP (g)	DCP (g)	MADC (g)	CP/DE	MADC/NE
Good grass hay (n 62)*	850	2.34	1.34	333	102	59	50	44	37
Poor grass hay (n 70)*	850	1.69	0.92	382	76	37	31	45	34
Barley grain (n 120)*	860	3.56	2.55	54	117	92	92	33	36
Soyabean meal extracted 48-50 (N 130)*	883	4.20	2.40	39	545	496	496	130	207

* Tables INRA 1984

The energy value (DE or NE per kg DM) and nitrogen value (CP or MADC, per kg DM) of each diet and the amount of feed required to meet energy and nitrogen requirements were computed in each energy and nitrogen system. In a first approach, the hay to concentrate ratio was that proposed by NRC (1989). Then, in a second step, the hay to concentrate ratio tested was that proposed by INRA (1990).

For the lactating mare fed a hay and concentrate diet supplemented with the same concentrate percentage proposed by NRC, TDMI of rations are 10 to 13% higher with INRA rations than with NRC rations at 1st month of lactation, according to quality of hay. Thereafter differences come to be erratic (0.1 to 7.2%). For mares fed a hay and concentrate diet supplemented with the concentrate percentage proposed by INRA, TDMI of INRA rations are 14 to 18% higher than the NRC ration in early lactation, according to hay quality. The differences decrease as late lactation approaches. As a result DE provided by balanced rations calculated in the INRA system supplemented with concentrate percentage proposed by INRA are 5 to 19% higher than DE requirement (NRC) in the first and fourth months of lactation; NE provided by a NRC ration calculated in the NRC system supplemented by adequate concentrate percentage in the NRC approach are 3 to 10% lower than NE requirements (INRA) (Table 18).

Discrepancies are very difficult to interpret further, as there are strong interactions either with the relative NRC/INRA requirements (energy and protein), and the evolution of the requirement during lactation (Table 15), or with the hay and concentrate substitution rate on DM basis and to the respective protein/energy ratios of hay, barley and soybean (Table 17) in each system.

Table 18. Comparison of balanced rations calculated in either the NRC or INRA system balanced for energy and protein for the mare in the 1st month of lactation (BW = 500 kg).

		DM (kg)	C (%)	DE (Mcal)	CP (g)	NE (Mcal)
NRC	Hay (good)	5.00		11.70	510	6.70
	Barley	4.30	50	15.31	503	10.96
Requirements	Soyabean	0.70		3.94	382	1.68
28.3 Mcal DE		10.00		30.95	1395	19.34
1427 g CP 2.0 < TDMI % BW	< 3.0	(2.0 % BW)		NE provided by NRC ration / NE requirements (INRA)		= - 2.22 Mcal (- 10 %)

		DM (kg)	C (%)	NE (Mcal)	MADC (g)	DE (Mcal)
INRA	Hay (good)	7.26		9.73	363	17.00
	Barley	4.27	39	10.88	392	15.20
Requirements	Soyabean	0.36		0.86	179	1.51
21.56 Mcal NE		11.89		21.47	934	33.71
950 g MADC 2.4 < TDMI % BW	< 3.0	(2.4 % BW)		DE provided by INRA ration / DE requirements (NRC)		= +5.41 Mcal (+ 19 %)

For the pregnant mare fed a good hay and concentrate diet supplemented with the same concentrate percentage proposed by NRC, the TDMI differences between NRC and INRA rations are erratic, mainly in regard to early pregnancy. DE provided by INRA balanced rations are 5 to 7% lower (8th-9th month and 11th month, respectively) or 2% higher (10th month) than the NRC requirements. For mares fed only a good hay-based diet, TDMI of a INRA balanced ration are 4 to 11% higher than NRC ration from 8th-9th months to the 11th month. DE provided by this balanced good hay INRA ration calculated in the INRA system is 10% higher than DE NRC requirements in late pregnancy (10th-11th month) and the difference varies as the quality of hay decreases. But the differences become erratic as soon as rations are supplemented with concentrate percentage proposed by NRC.

For the yearling (12 months) fed good hay supplemented with the concentrate percentage proposed by NRC, TDMI differences between NRC and INRA balanced rations are erratic, ± 4 to 19% for rapid (0.750 kg/d) and moderate growth (0.450 kg/d). But DE provided by balanced good hay and concentrate ration calculated in the INRA system are 5 to 16% lower than the DE NRC requirements for moderate and rapid growth, respectively. Conversely, the NE provided by the NRC balanced diet calculated in the NRC system is 8 to 19% higher than INRA requirements for moderate and rapid growth (Table 19), respectively. And 60% concentrate for moderate growth suggested by NRC appears to be far too high in the INRA system; 40 % could be more appropriate.

For the two-year-old (24 months) not in training, fed good quality hay with 35% concentrate as proposed by NRC, TDMI differences are erratic, ± 6% between NRC according to the growth rate (+ 6% for INRA ration when 0.200 kg/d and - 6 % when 0.450 kg/d). But the DE provided by a balanced ration calculated in the INRA system are lower (- 4%) than DE according to NRC requirements, primarily for rapid growth. And NE provided by a balanced ration calculated in the NRC system are 5% higher for rapid growth and -5% for moderate growth.

Table 19. Comparison of rations calculated in each NRC and INRA system balanced for energy and protein for the growing horse.

Yearling 12 month - Rapid growth 0.750 kg/d - BW = 320 kg

NRC		DM (kg)	C (%)	DE (Mcal)	CP (g)	NE (Mcal)
		2.80		6.55	286	3.75
		3.54	60	12.6	414	9.03
Requirements		0.66		2.77	359	1.58
21.7 Mcal NE		7.00		21.92	1059	14.36
1083 g CP		(2.2 % BW)		NE provided by NRC ration / NE requirements INRA		= + 2.26 Mcal (+ 19 %)
2.0 < TDMI % BW	< 3.0					

INRA		DM (kg)	C (%)	NE (Mcal)	MADC (g)	DE (Mcal)
	Hay (good)	2.39		3.20	120	5.59
	Barley	3.12	60	7.96	287	11.10
Requirements	Soyabean	0.39		0.93	193	1.64
12.1 Mcal NE		5.90		12.82	600	18.33
590 g MADC		(1.8 % BW)		DE provided by INRA ration / DE requirements NRC		= - 3.37 Mcal (- 16 %)
1.7 <TDMI % BW	< 2.5					

As in the mare, interpretation of the discrepancies is confusing as to NRC/ INRA requirements; NRC requirements are lower than INRA requirements (Table 15). In addition, there is a strong interaction with hay and concentrate substitution either on DM and/or energy. Hay to concentrate ratios based on TDMI % BW suggested by NRC 1989 are rather high and very close to the maximum feed intake capacity of the growing horse fed hay ad libitum supplemented with a very high percentage of concentrate.

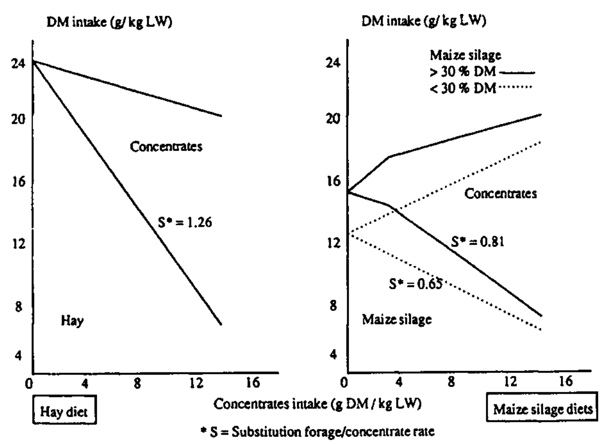


Figure 7. Effect of concentrate supplementation on forage and diet intake in young horses (12 months of age) (Agabriel et al., 1982 ; Martin-Rosset and Doreau, 1984b).

Forage-concentrate substitution on DM basis is well known in growing horses in the INRA system (Figure 7). Forage intake decreases in the yearling (12 months) when the amount of concentrate rises in the diet. The decreasing amount of forage DM intake, so-called substitution rate, is on average 1.26 with hay (NE = 1.14 to 1.34 Mcal NE/kg DM) but it reaches only 0.73 for maize silage (NE = 1.78 - 1.87 Mcal NE/kg DM). And the effect of substitution might rise with the age of the growing horse (Martin-Rosset and Doreau, 1984b). As a result, it becomes easier to understand NRC, assuming a high percentage TDMI/BW. For example, with a 2-3% BW for a yearling higher on average than INRA TDMI % (BW = 1.72-2.50%), the DE requirement can be easily reached with a high percentage of concentrate, even though amount of forage intake is restricted by substitution. Conversely, the amount of hay intake in the INRA ration is more restricted for the substitution ratio on an energy basis (and nitrogen basis as well) and should be much higher due to MADC/NE ratio of hay and soyabean meal. The figure could be discussed for the two-year-old as well. In the older, growing horse (2 or 3 years old), as requirements decrease, intake capacity increases and ingestibility of forage is not very limiting. As a result, the high proportion of concentrate suggested by NRC (35 %) is not appropriate in the INRA system.

For the working horse, direct comparisons are impossible as definitions of the work intensities are different between NRC and INRA. As a result, requirements are different (Table 15 and Figure 4). After attempting adjustments of INRA work intensities and requirements to NRC proposals, comparisons were attempted with good hay-based diets supplemented with the percentage of concentrate proposed by NRC. TDMI is higher with NRC rations than with INRA regardless of work intensity, but it was impossible to balance INRA rations for MADC requirements, as NRC percentages of concentrate are far too high to be consistent in the INRA system. However, DE provided by the INRA rations was 12 to 18% lower than DE NRC requirements.

The rations were recalculated in each system with a good hay diet supplemented with a lower percentage of concentrate and the addition of some wheat straw to fit the MADC requirements in the INRA ration. TDMI was 2 to 19% higher for INRA rations than for NRC rations.

Validity of the energy systems

Agreements or differences in feed allowances among systems, even with the same feeds and diets, do not allow conclusions to be drawn about the validity and accuracy of each system. Animals respond to inadequate rations through changes in production (milk, weight gain or performance), body weight and body composition.

In France, the validity of the NE (UFC) system was evaluated using two data files, feeding trials performed at INRA with different diets based on hay (Agabriel et al., 1982; Agabriel et al., 1984; Vermorel et al., 1984; Martin-Rosset and Doreau, 1984b; Bigot et al., 1987; Doreau et al., 1988a,b; Martin-Rosset et al., 1989; Doreau et al., 1991; Martin Rosset and Vermorel, 1991; Micol and Martin-Rosset, 1995), hay, maize silage, hay-straw and supplemented with concentrates containing cereals, soyabean meal, dehy-alfalfa and bran according to type of animal (mares, growing horses, exercising horses). Data concerning stallions were provided by bibliography (Axelsson, 1949; Jespersen, 1949) and survey in the stable of the French National Studs (n = 1600 stallions).

Calorimetry studies were carried out with horses at maintenance fed 12 different diets (Vermorel et al., 1996) and compared with results obtained in long-term feeding trials with horses fed the same diets at maintenance (Martin-Rosset and Vermorel, 1991) or in working horses (Vermorel et al., 1984; Martin-Rosset et al., 1989).

Tables of nutrient concentration in total diet using NE and MADC systems (Tables 20 -24)

Tables of daily nutrients (allowances) have been stated for horses of different weights in each breed: 400 to 600 kg for light breeds (namely sport and leisure horses) and 700 to 800 kg for heavy breeds. All types of horses are included (stallions, geldings, mares, growing horses and exercising horses) (Tables 20-24).

For horses at maintenance, effect of genetic type is included for the appropriate BW for sport horses (Tables 20 to 22) and for heavy horses (Tables 23-24). For bloodstock (400-500 kg), this calculation should be performed: maintenance energy requirement of gelding in stricto sensu maintenance + 10%; energy requirement for geldings at rest during the period of training is stricto sensu maintenance + 15%; for stallions out of breeding season stricto sensu maintenance + 20 %.

For mares, two levels of energy and protein allowances are provided in pregnancy and lactation according to the breed and the body condition score in each breed reached at the 8th month of pregnancy and at foaling.

For growing horses, allowances for young horses before weaning is not yet stated. But it could be determined in the very near future using a relationship between milk yield of the mare, determined with an original method (Doreau et al., 1986) and the average daily gain of the foal (Doreau et al., 1986), considering the effect of age at weaning (Warren et al., 1998) and the effect of concentrate supplementation of the foal on the growth (Martin-Rosset and Doreau, 1984; Breuer, 1998). After weaning, three categories of age are stated for sport-leisure horses and heavy breeds. Energy and protein allowances are provided for two growth rates in accordance with the growth curve and management stated for young light breed horses (Figure 5). Similar curves and management for young heavy horses have been performed (Micol and Martin-Rosset, 1995).

For working horses, descriptions of work intensities of light breeds are those described in Figure 4.

Lysine requirements are provided by NRC (1978 and 1989) and are 0.5% and 0.4% DM for yearlings and two-year-olds (and three-year-olds by extension). It is not stated for mature horses in Tables 20 and 24 as lysine requirements are not very well known. Ca, P, Mg, Na and K requirements are those drawn from NRC

(1978) and based on the work of Schryver and Hintz between the years of 1970 and 1978. Trace element and vitamin requirements are those drawn from the recommendations of Meyer (1982) and Wolter (1975), respectively. All these allowances are given in optimum concentration of TDMI (Table 14). TDMI proposed in these tables (20 to 24) are generally similar to or lower than those stated by NRC (1989), particularly for the growing horse. Diet proportions are given for each type of horse (Table 25). Ranges of concentrate and forage percentages are preferably provided as they take much more into account :

(1) concerning the feedstuffs - the types of forages and concentrates which are available to horse breeders and horsekeepers, the large variations of forage quality, possible use of some good straw in some situations;

(2) concerning the animal - the feed intake capacities of the different types of horses which have been measured in the interaction of body condition score according to INRA method (INRA - Institut du Cheval - Institut Elevage, 1997) based on slaughter experiments.

The concentrate percentages proposed by INRA are in most cases lower than those stated in NRC (1989) tables. The INRA proposals for energy, protein and feed intake capacity have been stated both on factorial and feeding experiments. Ingestibility of forages has been measured as well, and nutritive value of forages can be accurately predicted in the INRA system (Table 3 and appendix A, B, C).

Discussion - Conclusion

At the beginning of the 19th century, German and French workers carried out a lot of experiments which provided new promising scientific bases in equine nutrition. But after World War II scientific work declined tremendously in western Europe and to a lesser extent in eastern Europe and in the USA. As a result, horses were fed during this period using mostly the feed evaluation systems stated for ruminants which was inappropriate, as we know very well now.

In the 1960s, new research arose in the USA (H.F. Hintz was a pioneer in that field) and in the 1970s in Europe. The NRC of the USA published the first new feed evaluation systems for equines in the 1980s, the DE and DCP systems. These systems have been used to some extent in European countries. In 1989, NRC proposed a CP system instead of DCP system for evaluating nitrogen value of feeds.

In the 1980s and 1990s, INRA from France has proposed two new feed evaluation systems, the NE (UFC) and MADC systems. The difference in utilization efficiency of digestion end products involves large variations in the efficiency of DE or ME utilization and justifies expression of the energy value of feedstuffs in NE. The validity of the system was tested extensively.

In the MADC system, nitrogen value of feedstuffs in horses is linked to crude protein content (and NPN/N ratio), to digestibility of crude protein and respective proportion of crude protein digested either in the small intestine or in the large intestine. Total digestibility of CP has been extensively measured in equines for forages and to a lesser extent for concentrates. Proportion of CP digested in the small and large intestine is now much more well known thanks to experiments carried out with fistulated equines in the USA and Europe. Recent studies of Brazilian researchers support the coefficient of true N digestibilities stated in the MADC system in the small intestine. Amino acid requirements are mainly supplied by AA absorbed in the small intestine when horses are fed a high proportion of concentrates. At the same DCP content, concentrates provide 20 to 40% more AA than forages. The difference between forages and concentrates might be reduced as forages provide some essential AA and nitrogen sources, AA and/or ammonia to microbial population in the large intestine for synthesizing microbial protein. If the AA absorption in the large intestine should be considered very negligible, which might be the case, the MADC system would account for any amount of AA (and ammonia) which are used by microflora to satisfy its own nitrogen requirements in respect to amount of available energy (Glade, 1984; Reitnour, 1979-1980). Bacteria are known to be able to use AA (and NPN) for synthesizing their own protein which is then digested partially by microbial enzymes (Baruc et al., 1983). Net absorption of nitrogen is as high in the small colon as in the cecum (Glade, 1983). Amount of urea recycled is estimated (Prior et al., 1974) and efficiency of available urea or ammonia for microbial protein synthesis is estimated as well (Hintz and Schryver, 1972 ; Slade et al., 1973). Microbial protein accounts for 50 to 60% of total nitrogen in the feces (Meyer et al., 1963).

Energy and protein requirements and recommended allowances stated in the NE and MADC systems are consistent for the different types of equines as they have been extensively checked with long-term feeding experiments, but allowances for intense exercise in light horses need to be refined more accurately in relation to the training method.

These systems are now used in southern European countries where the INRA handbook has been translated into Italian and Spanish and in Northern European countries where the last meeting of the European Association of Animal Production (EAAP) was held in Iceland in 1993 and then in Norway in 1996. Eastern countries such as Poland and Romania are using them as well. In other countries the question is still open. For that purpose, the English version of the INRA handbook is in progress.

DAILY NUTRIENT ALLOWANCES

Key notes for using Tables 20 to 25

* Body weight 24 h after foaling in good conditions

** The lower values are used with high proportion of concentrates in the diet and the higher values are used with hay-based diet

(1) Riding horses are mainly considered in the table (For bloodstock see paragraph 2.6)

(2) For bloodstock, requirements have to be increased (see paragraph 2.6)

(3) Includes 1 hour of daily light work for stallions managed in box or in paddock

(4) This DM intake accounts for limited straw intake as well

(5) Light breeds :
- For mares whose offspring are used in competition with the exception of mares that are fat (BCS (4)) (INRA, 1990)
- Other mares (BCS (2.5)) and mares wintered outdoors or mares 3 years old

(6) Light breeds: other situations

(7) Geldings and mares are covered by these allowances.
For stallions add daily 0.88 Mcal and 30 g MADC

(8) For 2 hours work (average daily work in riding school)

(9) In case of working outside consider :
- very light work = 1 hour riding out ;
- light work = 2 hours riding out
- for long hacking: light work = 2-4 hours riding out ;
  moderate work = riding out over 4 hours

(10) For 1 hour of daily work

(11) Not in training (for training see Figure 4)

(12) Lysine: - 0.5 % DM 12 months
- 0.4 % DM 24 months and 36 months

(13) Heavy breeds: for lean mares (BCS < 2.5), mares managed outdoors

(14) Heavy breeds : other situations

(15) Hay cutting, wilting, etc.

(16) Plowing soft land or harrowing

(17) Plowing heavy land

Table 20: Daily nutrient allowances of horses 400 kg(1)(2)

Animal	Weight (kg)	Daily gain (kg)	NE (Mcal)	MADC (g)	Lysine (g)	Ca g)	P (g)	Mg (g)	Na (g)	K (g)	Vit. A (10^3IU)	DM** (kg)
Mature horses												
- MAINTENANCE(2)	400		7.89	230		20	12	5	16	27	22	6.0-7.5
- STALLIONS	400											
• Out of breeding season(3)			10.35	305		24	12	8	22	32	26	7.0-9.0(4)
• Breeding season = service												
Light			13.86	460		28	15	8	25	39	32	8.5-10.0(4)
Moderate			15.62	530		32	15	8	34	53	39	9.5-11.5(4)
Intense			16.94	600		34	15	8	36	56	42	10.5-12.0(4)
- MARES			LL(6) HL(5)									
• Pregnant	400*											
Before 8th month (or dry)			7.04 8.80	255		21	11	5	10	25	26	5.0-7.5
8th-9th months			7.70 9.46	290		25	14	5	10	27	28	5.5-8.0
10th month			8.80 10.34	390		32	23	5	10	30	32	6.0-9.0
11th month			8.90 10.56	415		33	22	5	10	32	34	6.5-9.5
• Lactating												
1st month			16.50 19.58	780		57	49	8	14	35	40	10.0-13.0
2nd-3rd months			14.08 16.72	680		46	36	7	14	32	37	8.0-13.0
4th month to weaning			11.22 13.86	550		38	30	7	14	26	30	6.5-10.5
- WORKING HORSES(7)	400											
• Rest			8.26	240		20	12	5	16	27	22	6.0-7.5
• Very light(8)(9)			10.56	330		22	12	6	20	32	26	7.5-8.5
• Light(8)(9)			13.86	430		24	13	6	35	38	31	8.5-10.5
• Moderate(8)(9)			16.06	490		29	15	8	45	55	41	9.5-12.5
• Intense(10)			14.52	450		29	15	8	38	50	38	9.0-11.0
Growing horses												
• Yearling : 12 months(12)												
- rapid growth	280	0.6-0.7	10.34	530	30	33	18	8	10	18	21	5.0-7.0
- moderate growth	260	0.3-0.4	8.58	360	28	31	12	8	8	17	19	4.5-6.5
• Two-year-old: 24 months(11)(12)												
- rapid growth	390	0.3-0.4	12.76	340	29	32	18	8	11	13	25	6.0-8.5
- moderate growth	360	0.1-0.15	11.00	270	27	30	12	8	8	12	24	5.5-8.0
• Three-year-old: 36 months(11)(12)												
- Rapid growth	400	01-0.15	11.66	270	31	26	12	8	10	11	27	6.5-9.0
- Moderate growth	380	0.-0.1	11.44	200	29	24	13	8	11	10	25	6.0-8.5

Table 21: Daily nutrient allowances of horses 500 kg(1)(2)

Animal	Weight (kg)	Daily gain (kg)	NE (Mcal)	MADC (g)	Lysine (g)	Ca g)	P (g)	Mg (g)	Na (g)	K (g)	Vit. A (10^3IU)	DM** (kg)
Mature horses												
- MAINTENANCE(2)	500		9.29	270		25	15	7	18	31	25	7.0-8.5
-												
- STALLIONS	500											
• Out of breeding season(3)			11.85	360		28	15	10	24	36	29	8.0-10.0(4)
• Breeding season = service												
Light			14.52	480		30	18	10	28	41	33	9.5-11.0(4)
Moderate			16.45	550		32	18	10	31	41	33	10.5-12.5(4)
Intense			17.60	620		34	18	10	39	61	46	11.5-13.0(4)
- MARES												
• Pregnant	500*		LL(5) HL(6)									
Before 8th month (or dry)			8.36 10.12	295		25	15	7	12	29	30	6.0-8.5
8th-9th months			9.02 11.0	340		29	18	7	12	31	33	6.5-9.0
10th month			10.34 12.54	460		38	26	7	12	35	37	7.0-10.5
11th month			10.56 12.76	485		39	28	7	12	37	39	7.5-11.0
• Lactating	500*											
1st month			19.58 23.54	950		61	55	10	15	41	47	12.0-15.0
2nd-3rd months			16.72 20.24	800		47	40	9	14	38	44	10.0-15.0
4th month to weaning			13.42 16.50	660		39	32	8	13	31	36	8.0-12.5
- WORKING HORSES(7)	500											
• Rest			9.73	290		25	15	7	18	31	25	7.0-8.5
• Very light(8)(9)			11.88	370		28	16	8	22	36	29	8.5-9.5
• Light(8)(9)			15.18	470		30	18	9	37	53	39	9.5-11.5
• Moderate(8)(9)			17.38	540		35	19	10	47	60	45	10.5-13.5
• Intense(10)			15.95	490		35	29	10	40	55	41	10.0-12.0
Growing horses												
• Yearling : 12 months(12)												
- rapid growth	320	0.7-0.8	12.10	590	33	39	22	10	12	20	23	5.5-8.0
- moderate growth	280	0.4-0.5	9.90	440	31	28	16	9	9	19	22	5.0-7.5
• Two-year-old: 24 months(11)(12)												
- rapid growth	470	0.4-0.5	14.96	420	35	36	20	10	13	16	31	7.5-10.0
- moderate growth	440	0.15-0.25	13.20	330	33	28	16	9	12	15	29	7.0-9.5
• Three-year-old: 36 months(11)(12)												
- Rapid growth	490	015-0.25	14.3	330	38	30	18	10	12	13	33	8.0-11.0
- Moderate growth	470	0-0.10	13.2	260	35	25	15	8	12	12	31	7.5-10.0

Table 22: Daily nutrient allowances of horses 600 kg(1)(2)

Animal	Weight (kg)	Daily gain (kg)	NE (Mcal)	MADC (g)	Lysine (g)	Ca g)	P (g)	Mg (g)	Na (g)	K (g)	Vit. A (10^3IU)	DM** (kg)
Mature horses												
- MAINTENANCE	600		10.69	310		30	18	8	24	35	28	8.0-9.5
- STALLIONS	600											
• Out of breeding season(3)			13.42	420		30	18	9	27	40	33	9.0-11.0(4)
• Breeding season = service												
Light			15.18	500		36	21	10	30	45	37	10.5-12.0(4)
Moderate			17.25	570		36	21	11	34	63	47	11.5-13.5(4)
Intense			18.80	640		36	21	12	42	66	50	12.5-14.0(4)
- MARES	600*		LL(6) HL(5)									
• Pregnant												
Before 8th month (or dry)			9.46 11.66	340		30	18	7	15	32	34	6.5-9.5
8th-9th months			10.34 12.54	395		35	22	8	15	35	37	7.0-10.5
10th month			11.88 14.52	535		46	32	8	15	41	43	8.5-12.0
11th month			12.10 14.74	565		47	34	8	15	41	43	8.5-12.0
• Lactating												
1st month			23.10 27.72	1125		73	67	11	18	47	55	14.0-17.5
2nd-3rd months			19.58 23.54	960		57	48	10	17	44	52	12.0-17.5
4th month to weaning			15.62 19.14	780		47	38	9	16	36	42	9.5-14.5
- WORKING HORSES(7)	600											
• Rest			11.20	330		30	18	8	24	35	28	8.0-9.5
• Very light(8)(9)			13.20	415		33	19	9	25	40	33	9.5-10.5
• Light(8)(9)			16.50	510		33	21	10	40	46	37	10.5-12.5
• Moderate(8)(9)			18.70	580		38	22	11	50	65	49	11.5-14.5
• Intense(10)			17.16	530		42	22	11	43	60	45	11.0-13.0
Growing horses												
• Yearling : 12 months(12)												
- rapid growth	360	0.8-0.9	13.64	660	39	44	24	12	13	23	27	6.5-9.0
- moderate growth	320	0.5-0.6	11.44	510	35	33	18	11	11	21	24	6.0-8.0
• Two-year-old: 24 months(11)(12)												
- rapid growth	530	0.5-0.6	17.16	480	41	42	24	10	15	19	36	8.5-12.0
- moderate growth	500	0.25-0.35	14.96	390	38	33	19	10	13	17	33	8.0-11.0
• Three-year-old: 36 months(11)(12)												
- Rapid growth	580	025-0.35	16.72	390	44	37	22	10	15	16	39	9.0-13.0
- Moderate growth	550	0.-0.10	14.96	320	41	29	17	11	14	14	36	8.5-12.0

Table 23: Daily nutrient allowances of horses 700 kg[(1)(2)]

Animal	Weight (kg)	Daily gain (kg)	NE (Mcal)	MADC (g)	Lysine (g)	Ca g)	P (g)	Mg (g)	Na (g)	K (g)	Vit. A (10^3IU)	DM** (kg)
Mature horses												
MAINTENANCE	700		11.37	340		30	18	9	26	38	31	9.0-10.0
STALLIONS	700											
• Out of breeding season[(3)]			13.42	430		35	21	12	30	49	35	10.0-12.0[(4)]
• Breeding season = service												
Light			14.76	480		37	24	12	32	48	39	11.0-13.0[(4)]
Moderate			16.43	540		38	24	12	42	66	50	12.0-14.5[(4)]
Intense			17.50	590		42	24	12	45	70	53	13.0-15.0[(4)]
MARES			LL[(14)] HL[(13)]									
• Pregnant	700*											
Before 8th month (or dry)			9.24 11.44	380		35	21	7	17	32	34	6.5-9.5
8th-9th months			9.90 12.32	445		41	26	8	17	36	38	7.0-11.0
10th month			11.44 14.30	570		53	37	9	17	40	42	8.0-12.0
11th month			11.66 14.74	600		55	40	9	17	40	42	8.0-12.0
• Lactating												
1st month			23.54 28.6	1295		85	78	13	21	54	63	14.5-21.5
2nd-3rd months			19.80 24.2	1045		66	56	11	20	45	53	12.0-18.5
4th month to weaning			15.62 19.58	860		55	45	10	19	38	44	9.5-15.5
WORKING HORSES	700											
• Rest			11.95	350		30	21	9	7	38	31	9.0-10.0
• Light (6 h/d)[(15)]			16.06	510		38	25	10	35	49	40	11.5-13.0
• Moderate (5 h/d)[(16)]			17.60	550		42	26	13	46	69	52	12.5-15.0
• Intense (4 h/d)[(17)]			20.90	645		49	26	13	57	74	55	13.5-16.0
Growing horses												
• Yearling : 12 months[(12)]												
- rapid growth	450	0.9-1.0	15.18	750	43	57	22	13	16	26	29	7.5-9.5
- moderate growth	410	0.6-0.7	12.32	590	39	40	23	11	14	24	27	7.0-8.5
• Two-year-old: 24 months[(11)(12)]												
- rapid growth	600	0.5-0.6	15.40	570	44	45	26	12	17	20	39	10.0-12.0
- moderate growth	560	0.2-0.3	13.20	440	42	36	21	11	15	19	37	10.0-11.0
• Three-year-old: 36 months[(11)(12)]												
- moderate growth	640	0-0.1	13.42	380	46	36	21	12	16	16	40	11.0-12.0

Table 24: Daily nutrient allowances of horses 800 kg(1)(2)

Animal	Weight (kg)	Daily gain (kg)	NE (Mcal)	MADC (g)	Lysine (g)	Ca g)	P (g)	Mg (g)	Na (g)	K (g)	Vit. A (10^3IU)	DM** (kg)
Mature horses												
- MAINTENANCE(2)	800		12.54	3.70		33	20	10	28	42	34	10.0-11.0
-												
- STALLIONS	800											
• Out of breeding season(3)			14.74	440		37	23	14	32	48	39	11.0-13.0(4)
• Breeding season = service												
Light			15.99	490		40	25	14	35	52	42	12.0-14.0(4)
Moderate			17.67	555		41	23	14	46	71	53	13.0-15.5(4)
Intense			18.75	600		44	24	14	48	75	56	14.0-16.0(4)
- MARES			LL(14) HL(13)									
• Pregnant	800											
Before 8th month (or dry)			10.12 12.54	420		40	24	7	15	35	28	7.0-10.5
8th-9th months			11.00 13.64	495		46	30	8	17	39	41	8.0-11.5
10th month			12.76 15.84	630		61	42	10	20	44	46	9.0-13.0
11th month			12.98 16.28	660		62	46	10	20	44	46	9.0-13.0
• Lactating												
1st month			26.18 32.12	1470		98	89	14	24	61	71	16.0-24.5
2nd-3rd months			22.22 27.06	1180		76	64	13	23	51	60	13.5-20.5
4th month to weaning			17.38 21.78	930		62	51	11	22	41	47	10.5-16.5
- WORKING HORSES	800											
• Rest			13.17	390		33	20	10	28	42	34	10.0-11.0
• Light (6 h/d) (15)			17.16	510		38	25	11	38	53	43	12.5-14.0
• Moderate (5 h/d) (16)			18.70	550		43	28	14	45	74	55	13.5-16.0
• Intense (4 h/d) (17)			22.00	650		54	30	14	52	79	59	14.5-17.0
Growing horses												
• Yearling : 12 months(12)												
- rapid growth	500	1.0-1.1	17.16	820	48	57	32	14	18	29	33	8.5-10.5
- moderate growth	460	0.7-0.8	14.30	660	43	46	26	13	15	26	29	8.0-9.0
• Two-year-old: 24 months(11) (12)												
- rapid growth	680	0.60-0.65	16.94	600	48	51	29	12	19	22	42	11.0-13.0
- moderate growth	640	0.30-0.40	14.74	490	46	42	24	12	17	21	40	11.0-12.0
• Three-year-old: 36 months(11) (12)												
- moderate growth	730	0.00-0.10	14.96	410	50	37	24	13	16	18	44	12.0-13.0

Table 25: Nutrient concentration in total diets for horses (dry matter basis)

	NE (Mcal/kg)	MADC (%)	% MADC/NE	DM % BW	Diet proportions Concentrate %	Forage(1) %		Comments
Mature horse								
MAINTENANCE	1.20	3.5	29	1.4 1.9	0	100		Hays M to G//
STALLIONS	1.28 1.36	3.9 4.5	32	1.4 + 3.0	5 15 30 - 40	85 95 60 70	Out of br .season service	Hays M to VG // + Straw// Hays M to VG // + Straw //
MARES								
• pregnant								
8 9th months	1.14 - 1.40	4.6	36	1.0 2.0				
10th month	1.16 1.41	5.4	42	1.1 2.3				Forages G↑ to VG//
11th month	1.16 1.42	5.6	43	1.1 2.4	5 - 50	50 - 95		Forages M↑ to VG//
• Lactating								
1st month	1.39 1.68	7.1	46	2.0 3.3				
2nd - 3rd months	1.32 1.60	6.6	45	1.7 3.3				
4th month to weaning	1.29 1.59	6.6	46	1.3 2.6				
WORKING HORSE								
Rest	1.25	3.7	31	1.3 1.9				
Light work	1.37	4.3	31	1.6 2.6	5 65	35 95	Light breed	Hay G to VG// + straw//
Moderate work	1.38	4.3	31	2.0 3.1	5 45	55 95	Heavy breed	Hay M to G// + straw//
Intense work	1.43	4.3	31	1.8 2.8				
Growing horse								
• Yearling : 12 months								
Rapid growth	1.75*-1.80**	8.7	49	1.7 2.5	35 60 40 - 60	40 65 40 - 60	Light breed Heavy breed	Forages G↑ to VG// or E// Forages G↑ to VG//
Moderate growth	1.59*-1.64**	7.2	45	1.7 2.5	10 35 10 - 15	65 90 85 - 90	Light breed Heavy breed	Forages M↑ to G↑ Straw↑ + Hay G//
• Two-year-old: 24 months								
Rapid growth	1.41**-1.76*	4.9	32	1.6 2.3	20 25 40 60	75 80 40 -60	Light breed Heavy breed	Forages G to VG↑ or E// Forages G↑ to VG//
Moderate growth	1.26**-1.62*	4.1	28	1.6 2.2	15 20 10 - 15	80 85 85 - 90	Light breed Heavy breed	Forages M↑ or G// Straw↑ + Hay G//
• Three-year-old: 36 months								
Rapid growth	1.51*	3.5	23	1.5 2.2	15 20	80 85	Light or	Forages G//
Moderate growth	1.20**-1.58*	3.1	22	1.6 2.2	10 15	85 - 90	Heavy breed	Straw↑ + Hay G//

(1) straw is included in the hay percentages for stallions
(2) Straw is distinguished to indicate its specific mode of distribution
M Medium quality
G Good quality
VG Very good quality
E Excellent
↑ Forages offered ad libitum
// Forages restricted

* Light breed
** Heavy breed

APPENDIX

Routine laboratory methods for predicting the organic matter digestibility (and net energy) of FORAGES in the horse

A. from chemical composition
B. using enzymatic method
C. using near infrared spectrophotometry (NIRS)

A. from chemical composition

Prediction of organic matter digestibility (OMD) of forages in horses from chemical composition.

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INTRODUCTION

OMD coefficients of forages measured in vivo in horses are known to be the reference method, but they cannot be measured for all forages in view of predicting routinely their NE value in the UFC system. As a result, OMD must be predicted from chemical composition.

MATERIAL & METHODS

Botanical and crop characteristics of the 52 forages studied

types	species	number	1st cycle	regrowth
green forages	grassland	7	3	4
hays	grassland graminea	39	24	15
hays	legumes (lucerne)	6	0	6

Range of chemical composition and in vivo digestibility of the 52 forages

Ash (g / kg DM)	63-152
CP (g / kg DM)	55-214
CF (g / kg DM)	235-424
*CC (g / kg DM)	7-136
NDF (g / kg DM)	477-737
ADF (g / kg DM)	255-452
ADL (g / kg DM)	27-97
OMD (%)	41-66

* CC = water soluble carbohydrate

In vivo measurement of OMD

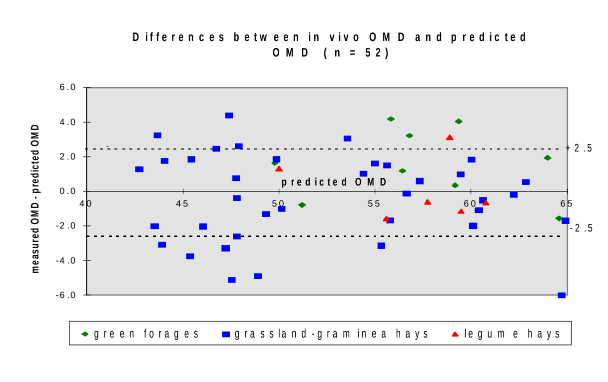
- 5-6 gelding horses 500 kg BW
- level of feeding : 1.2 times the maintenance requirement
- 2 weeks adaptation
- 6 days total feces collection

RESULTS

XΩμ OMD γ≤μππΔγΔμ◦ = of all the forages can be predicted with only one relationship :

$$\text{OMD (\%)} = 67.78 + 0.07088\ \text{CP} - 0.000045\ \text{NDF}^2 - 0.12180\ \text{ADL}$$

RSD = ±2.5 R† = 0.878 N = 52



The average differences between OMD predicted with this model and OMD measured in vivo are :
- 1.9 for green forages
0.0 for grassland and graminea hays
+0.06 for legume

CONCLUSIONS

XΩμ ~+μδ Δγ=Δ≤◦ μΩXα =Δ≤◦ ≤π π≤+αωμ−≥≥ βα−μδ ≤◦ • ‖√ > α◦ δ √≈ Δ−≤ XγΩ ≤ ≤+μ αγγX+α =μ ′+− 2.5″ =Ωα◦ =Ωμ π≤+≤ μ+{• +√ ≤ ≤δ μ<1984 X−Δ ω ≤◦ ≪∞ √ α−+− +α◦ ωμδ π+≤≤ 3.7 ≍ 60 δ μ~μ◦ δ Δ ω ≤◦ =Ωμ =∞~μ ≤π π≤+α ω μ

B. using enzymatic method

Prediction of organic matter digestibility (OMD) of forages in horses by pepsine cellulase method.

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INTRODUCTION

Chemical composition remains a medium quality estimator of OMD for horses especially when complex forages (natural grassland) are concerned. Enzymatic method using pepsine cellulase might be a suitable method.

MATERIAL & METHODS

Botanical and crop characteristics of the 52 forages studied

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OMD (%)	41-66

* CC = water soluble carbohydrate

In vivo measurement of dOM

- 5-6 gelding horses 500 kg BW
- level of feeding : 1.2 times the maintenance requirement
- 2 weeks adaptation
- 6 days total feces collection

Method of pepsine cellulase degradability of dry matter (CDMD) or of organic matter (COMD)

1) pre-treatment with pepsine in hydrochloric acid (0.2 % pepsin in 0.1 N HCL) in a water bath at 40 C for 24 h
2) starch hydrolysis in a water bath in the same mixture for exactly 30 min at 80 C
3) attack by cellulase (cellulase ONOZUKA R10) for 24 h in a water bath at 40 C, then filtration and rinsing.

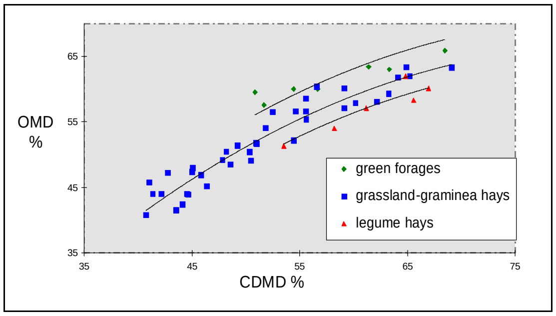
RESULTS

OMD (%) can be predicted for all forages from CDMD (%) with only one curvilinear relationship set up for the grassland and graminea hays, provided a correcting effect (di) due to the type of forage :

$OMD = -29.38 + di + 2.3032\ CDMD - 0.01384\ CDMD^2$

n = 52 RSD = ±1.90 R† = 0.927
di = + 4.12 for green forages
di = 0 for grassland - graminea hays
di = - 2.61 for legumes hays

For green forages and legumes hays, OMD prediction must be restricted to the CDMD range between 51 to 69 %.



CONCLUSION

OMD ≤π π≤+αωμ− γα◦ βμ ~+μδ Δγ=μδ +≤×=Δ μ≪ ×−Δ ω ~μ~−Δ μ γμ≪×≪α −μ ≤ μ=Ω≤δ ± Δ=Ω α βμ=μ+ αγγ×+αγ∞ ′+− ①⑨⓪″ =Ωα◦ π+≤≤ γΩμ≤ Δγα<γ≤≤ ~≤−Δ=Δ≤◦ ′+− ②⑤⓪″ μ−~μγΔα≪∞ π≤+γ≤≤ ~≪μ∅ π≤+αωμ−

C. using near infrared spectrophotometry (NIRS)

Prediction of organic matter digestibility (OMD) of forages in horses near infrared spectrophotometry (NIRS).

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INTRODUCTION

Routine laboratories need to use fast and accurate methods for predicting OMD and UFC value of forages. NIRS method might be the appropriate method.

MATERIAL & METHODS

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OMD (%)	41-66

* CC = water soluble carbohydrate

In vivo measurement of OMD

- 5-6 gelding horses 500 kg BW
- level of feeding :1.2 times the maintenance requirement
- 2 weeks adaptation
- 6 days total feces collection

NIRS method :

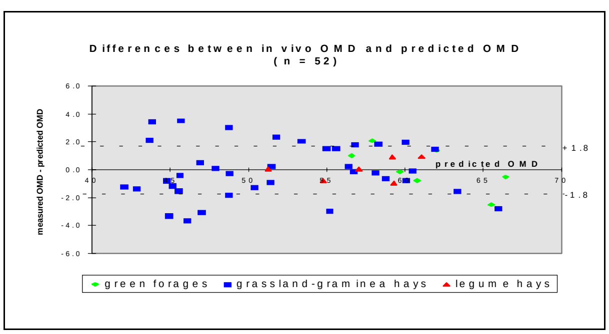
- forages were ground through a 0.8 mm screen
- dried again in an oven (40 C - one night)
- mononochromatic spectrophotometer (type 6500 Nirsystems)
- two reflectance spectra for each sample between 1100 to 2500 nm wavelengths
- calibration
- prediction

RESULTS

Accuracy of the calibration performed to predict OMD is very high

		52 forages		45 hays		39 hays (1)	
Results	Model (3)	R	SEC	R	SEC	R	SEC
Absorbance (derived functions)	stepwise	0.965	1.82	0.959	1.89	0.964	1.80
Absorbance (derived functions)	mpls	0.950	2.18 (2)	0.949	2.10 (2)	0.954	2.02 (2)

(1) grassland - graminea hays (2) standard error of cross validation
(3) stepwise = method of multiple linear regression; MPLS = modified partial least squares regression



OMD can be predicted with a single calibration as far as the green forages and lucerne hays are included in the data bank to perform the regression for all the forages (n=52).

CONCLUSION Accuracy of OMD prediction with NIRS method is as high as OMD prediction with enzymatic method, RSD = 1.80 and 1.90 respectively and NIRS is a much faster method.

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