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ADVANCES AND GAPS IN ENERGY NUTRITION

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Although energy is not a nutrient per se, it is one of the most important dietary essentials. The current Nutrient Requirements of Horses (NRC, 1989) provides recommendations for daily digestible energy (DE) intake of horses of various body weights during maintenance, gestation, lactation, growth and work. The text of the document provides an explanation of the derivation of the actual values, as well as discussion regarding energy source and feed intake. The nutrient requirements given in the 1989 publication represented what the subcommittee considered to be minimum amounts needed for normal health, production and performance. When possible, the committee based recommended daily energy intakes on published research reports. Because extensive research was not available for every class of horse, the subcommittee also used "calculations designed to extrapolate information over the total population" and/or "the subcommittee's experience in applying information to field situations" (NRC, 1989). Since 1989, enough new research in equine nutrition has been published to refine some (but not all) existing recommendations for daily energy intakes. There are also several topics that could be included in the text of the document or included in the tables. In the future, it may be possible to develop a multilevel model to estimate energy requirements in horses. A multilevel model would provide information in the same format currently available but could also provide flexibility to users who want to customize recommendations for specific situations.

Energy Requirements for Growth

Using the results of several studies with growing horses, the 1989 NRC determined DE requirements to be related to body weight (BW), average daily gain (ADG) and age. Body weight was used to determine the requirement for maintenance; ADG and age were used to estimate the amount of energy necessary for growth. The age component was necessary to account for differences in the efficiency of DE use for gain by horses of different ages. When DE recommendations in the 1989 NRC are compared to the recommendations in the previous edition (1978), it is obvious that the method adopted in 1989 resulted in significant changes to some of the values. For example, in 1978, the DE requirement for yearlings (500 kg mature weight; .55 kg ADG) was 16.8 Mcal/d. The 1989 value is about 17% higher (19.7 Mcal/d). One method of evaluating the accuracy of nutrient recommendations is to compare predicted values to values observed in actual feeding trials. Figure 1 depicts information from several growth trials reported in the last decade. The amount of DE necessary for the horses in each trial as predicted by the 1989 NRC (based on age, body weight and ADG) was calculated and compared to the actual amount of DE fed. Except in a few cases, the predicted value exceeded the actual requirement. Differences between predicted and actual DE intakes could be attributed to an incorrect prediction equation for

DE requirements. However, in most of the studies, the amount of DE intake fed was calculated from feed composition and not actually measured; therefore, some of the difference could be attributed to inaccuracy in estimating DE intake. In addition, the values in Figure 1 represent mean values for gender groups or various treatments within specific studies. To perform an accurate evaluation of the 1989 prediction equation for DE in growing horses, it will be necessary to have individual horse data.

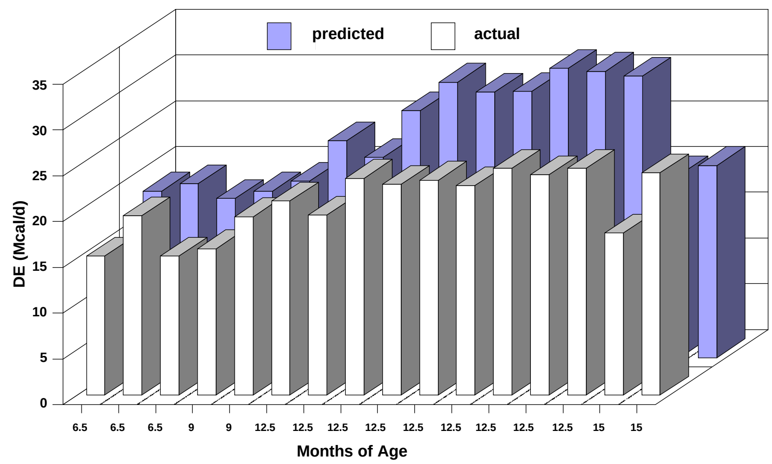

Figure 1. Predicted and observed digestible energy requirements of growing horses. (Calculated from data of Cymbaluk et al., 1990; Graham et al., 1994; Ott and Asquith, 1995; Ott and Kivipelto, 1999; Savage et al., 1993).

When the last edition of Nutrient Requirements of Horses was compiled, there were no studies on the DE requirements of long yearlings and two-year- olds in training. Clearly, this is an area where major gaps in knowledge still exist. The DE requirements in 1989 were formulated using the DE recommendations for horses in moderate work plus an allowance for gain. Since that time a number of studies have examined the nutrition of young horses in training (Hiney et al., 1999; Nielsen et al., 1993; Pagan et al., 1995; Pendergraft and Arns, 1993), but none have focused on DE requirements and these studies did not report enough information on DE intake or ADG to allow comparisons to the 1989 values.

In the 1978 edition of Nutrient Requirements of Horses, nutrient recommendations were included for nursing foals at three months of age. These recommendations were deleted in the 1989 edition but could be reinstated in the next version. Ideally, nutrient recommendations should be included for foals from birth. Information generated in the last decade on average growth curves in nursing foals (Breuer et al., 1996; Jelan et al., 1996; Pagan et al., 1996) could easily be combined with information on milk composition to estimate the nutrient requirements of foals from birth through two months of age. In addition, several papers have described daily gains under various milk replacement programs for early weaned foals (King and Nequin, 1989; Knight and Tyznik, 1985; Lawrence et al., 1991; Pagan et al., 1993). Recommendations for young foals should also consider the need for supplementation programs when different management programs are used (Breuer et al., 1996).

Energy Requirements for Reproduction and Lactation

The 1989 NRC recommends that pregnant non-lactating mares receive maintenance levels of DE intake during the first 8 months of gestation and that DE should be increased 11%, 13% and 20% above maintenance in the 9th, 10th and 11th months, respectively. These recommendations were based on the research of Meyer and Ahlswede (1978) that found the majority of fetal growth to occur in the last trimester of gestation. Two studies have reported weight changes in pregnant mares during various stages of gestation (Kowalski et al., 1990; Lawrence et al., 1992a). These studies found that pregnant mares entering the last trimester of gestation gain relatively little weight in that period. In one study, the majority of weight gain occurred in the second trimester of gestation. Neither study measured DE intake; however, the results of the studies could be used to provide guidelines for expected body weight gains in pregnant mares.

Digestible energy requirements for lactation are based on an expected milk production of 3% of BW in early lactation and 2% of BW in late lactation (NRC, 1989). Doreau and coworkers (1992) reported the mean milk production of French draft mares (725 kg) to increase from 2.6% BW in the first week of lactation to 3.9% BW in the eighth week of lactation. The mares in their study were given ad libitum access to high forage or high concentrate diets. Mares on the high forage diet consumed 50.8 Mcal DE/d in week four of lactation and were in positive energy balance based on an average daily gain of .18 kg. For the mares fed the high concentrate diet, mean daily DE intake at week four was 66 Mcal/d, and weight gain was 1.18 kg/d. Based on the responses to these two diets, the DE intake of these mares for lactation with zero body weight gain would be about 48 Mcal/d. Based on BW and actual milk production, the expected daily DE requirement (NRC, 1989) would be about 42 Mcal/d. Griewe-Crandell et al. (1997) fed 7 kg of concentrate and grass hay (ad libitum) to 575 kg lactating mares and reported that BW was maintained. If total feed intake is estimated at 2.5% of BW, the estimated energy intake of the lactating mares would have been about 40 Mcal/d, compared to the NRC (1989) estimate of 32 Mcal/d. For both studies, the actual intakes seem to be somewhat higher than the NRC (1989) recommended intakes.

In 1989, the DE requirement for breeding stallions was estimated to be similar to that for horses in light work (1.25 x maintenance). In 1993, Siciliano and coworkers reported results from a field study at a large central Kentucky stallion operation. The amount of feed offered per day was recorded by farm employees on a daily basis. Stallions were weighed once a month. Because the authors reported that data collected early in the study were more consistent than data collected later, only data from February and March will be used for comparison here. In February and March, when stallions were covering 5 to 25 mares per month, the amount of DE offered was just slightly higher than the 1989 recommendation for 600 kg stallions. The results suggest that the current recommendations are realistic, although the authors did not account for any pasture intake by the horses, which might have increased the difference between actual DE intakes and recommended DE intakes.

Energy Requirements for Work

In the fourth edition of Nutrient Requirements of Horses (1978), the only specific recommendations for energy intakes of horses performing different levels of work were found in a table in the text of the document (Table 1).

Table 1. DE use during various activities as listed in Nutrient Requirements of Horses (1978).

Activity	DE/hour (kcal) per kg BW (above maintenance)
Walking	0.5
Slow trotting, some cantering	5.0
Fast trotting, cantering, some jumping	12.5
Cantering, galloping, jumping	23.0
Strenuous effort (polo, racing)	39.0

To arrive at a daily DE intake for exercising horses using the 1978 NRC, users had to calculate the amount of energy used in work and add that to the maintenance requirement. In 1989, the subcommittee on horse nutrition adopted a more user-friendly approach, categorizing work as light, moderate, or intense, and estimating the daily DE requirements as 25%, 50%, and 100% above maintenance for these categories, respectively. The 1989 recommendations reflected a blending of information from controlled research studies, feeding surveys and practical experience. A number of studies published since 1989 can be used to evaluate the existing recommendations. Gallagher and coworkers (1992a;1992b) surveyed the diets of Thoroughbreds and Standardbreds in race training. Estimated DE intakes were 28 to 31 Mcal/d for Standardbreds (mean BW of 449 kg) and 31 to 36 Mcal/d for Thoroughbreds (mean BW of 505 kg). The NRC (1989) recommendations for intense work would be 28.8 Mcal/d for Standardbreds and 33 Mcal/d for Thoroughbreds. Southwood and coworkers (1993) in Australia reported daily DE intakes of 30.8 Mcal/d for Thoroughbreds and 31.5 Mcal/d for Standardbreds. In regard to moderate exercise, data from several controlled laboratory experiments can be compared to the NRC (1989) requirements. Taylor et al. (1995) reported that 420 kg horses undergoing moderate work three to four times per week maintained body weight when they received 19 to 22 Mcal DE/d. Using similar horses and a similar exercise program, Graham-Thiers et al. (1999) reported an ADG of .3 kg/d when horses received approximately 28 Mcal DE/d. The NRC (1989) recommendation for 420 kg horses in moderate work is about 21 Mcal/d. Powell (1999) reported that 540 kg horses working five days per week at a moderate intensity maintained BW when fed 27 Mcal/d. The

NRC (1989) recommendation is about 26.5 Mcal/d. Using the information from these studies, it appears that the NRC (1989) recommendations for moderate and intense work are relatively realistic. Because energy intake impacts body condition, several studies have surveyed body condition scores in horses involved in different athletic events. The results of these studies suggest that there is a broad range of acceptable condition scores for performance horses (Gallagher et al., 1992a and 1992b; Garlinghouse et al., 1999; Lawrence et al., 1992b).

Environmental Effects

The 1989 NRC states that all recommendations should be applied with consideration to digestive and metabolic differences among horses, health status, variation in nutrient availability in feed ingredients, previous nutritional status and climatic and environmental conditions. However, few data were available prior to 1989 to allow quantification of some of these considerations. One area that can now be quantified to some extent is the effect of environment on DE requirements. Cymbaluk and Christison (1990) reviewed studies with mature horses and growing horses. They suggested that the maintenance requirement of growing horses is increased by about 33% in cold housing conditions and by more than 50% in severely cold conditions. They also suggested that the daily maintenance requirement for mature, 500 kg horses is increased .408 Mcal of DE for every degree below the lower critical temperature (LCT). One of the difficulties in estimating environmental effects on requirements is determining the LCT. The LCT may vary for horses of different ages or body sizes and can change as horses become cold adapted. In addition, other factors such as presence of precipitation or wind will contribute to heat loss and result in increased maintenance energy requirements even though air temperature may be above the LCT. Data from other species such as dairy or beef cattle could be used to estimate the combined effects of wind, precipitation and cold on heat loss and maintenance energy requirements in horses.

Weight Gain in Adult Horses

The condition scoring system first introduced by Henneke and coworkers in 1983 has been widely accepted and used by nutritionists and managers within the horse industry. The 1989 NRC suggested that broodmares be maintained at a condition score of at least 5. For practical application of this recommendation, it is important to know how much weight gain is necessary to increase the body condition score of a mare from 4 to 5, and how much DE is required to accomplish this gain. This question is important for other groups of horses, including performance horses where weight lost during a long competition season may need to be replenished in a relatively short lay-up period. The 1989 publication indicated that an increase in condition score could be achieved if DE intake was increased 10 to 15% above maintenance. However, recent information suggests that this recommendation may not be realistic for many situations. The amount of DE required per kilogram of gain will depend on several factors including composition of gain and composition of diet. The amount of DE required per kilogram of gain typically increases with maturity. The NRC (1989) suggests that 19.8 Mcal of DE (above maintenance) are required per kg of gain by two-year-old horses. In a study by Heusner (1993) mature horses required approximately 24 Mcal of DE above maintenance per kilogram of gain. In the study by Graham-Thiers et al. (1999), a daily DE intake of 7 Mcal above maintenance and exercise resulted in an ADG of .3 kg, which suggests a value of 23 Mcal DE/kg gain. From these studies, it seems reasonable to estimate that at least 20 Mcal of DE are required per kilogram of gain for mature horses. Heusner (1993) found that weight gains of 33 to 45 kg were associated with an increase in condition score of approximately two units (from 4 to 6) in mature horses (approximately 480 to 580 kg). Consequently, it appears that each unit of condition score increase requires about 16 to 20 kg of weight gain. Using these assumptions, Table 2 shows the estimated amount of energy above maintenance required to increase the condition score of a horse from 4 to 5 over different periods of time.

Table 2. Estimated increase in DE intake necessary to change the condition score of a 500 kg horse from 4 to 5[A] .

Time Period to Accomplish Gain	Daily DE above Maintenance(Mcal/d)	% Increase in DE above Maintenance
60 d	5.3 to 6.7 Mcal	32 to 41%
90 d	3.6 to 4.4 Mcal	22 to 27%
120 d	2.7 to 3.3 Mcal	16 to 21%
150 d	2.1 to 2.7 Mcal	13 to 16%
180 d	1.8 to 2.2 Mcal	11 to 14%

[A] Assumptions: 1 unit of change of condition score requires 16 to 20 kg of gain and 1 kg gain requires 20 Mcal DE above maintenance.

Dietary Energy Sources

The principal sources of energy in typical equine diets are structural carbohydrates (SC) and nonstructural carbohydrates (NSC). High intakes of grain concentrates and other feeds high in NSC have been associated with increased risk of colic and laminitis. A potential addition to the next version of Nutrient Requirements of Horses would be a guideline on maximum amounts of nonstructural carbohydrates and/or minimum daily amounts of structural carbohydrates. Using ileal fistulated ponies and horses, researchers have now estimated the upper limit of starch digestion for the equine small intestine (Cuddeford, 1999; Potter et al., 1992). This information could be incorporated into the dietary energy recommendations to ensure feeding practices that promote the health and well-being of the horse. However, to make a maximum starch or NSC recommendation usable, it would be necessary to adjust the feed composition tables to include information on starch or NSC content. Describing minimum SC intakes could be approached by recommending daily minimum neutral detergent fiber (NDF) or acid detergent fiber (ADF) intakes. Information regarding the effect of ADF and NDF content of forages on voluntary intake could help refine the concentrate to forage ratios recommended for various classes of horses.

Considerable research has been conducted in the last 20 years on the effect of dietary energy form on metabolic and endocrine regulation in growing and working horses. Doreau et al. (1992) have demonstrated that dietary energy form can alter milk composition such that a high concentrate diet favors higher lactose production and a high roughage diet favors higher fat production. Despite the relatively large number of studies that have evaluated effects of different energy forms on horses, this area is still not completely understood. Further research is required to understand the relationships between energy source, energy amount and hormonal regulation of metabolism during growth, lactation and exercise.

Estimating Energy Requirements

Although many other species express energy requirements in units of metabolizable or net energy, the DE system still appears to be the most practical for horses. In 1989, the DE system was used because little information regarding the ME or NE value of common horse feeds was available. This situation still exists. However, because the amount of information regarding energy content of feeds may expand in the next decade, adding flexibility to the means of expressing and calculating energy requirements might be considered. One way to do this would be to design a multilevel model in which Level 1 is a straightforward listing of DE requirements using the same format as the 1989 Nutrient Requirements of Horses, and incorporating any necessary adjustments in current recommendations. In general, Level 1 would represent requirements for horses fed average diets in average environments. As in the current system, users would be able to specify some characteristics of the horse, such as mature body weight or rate of gain. In Level 1, users would not be able to change any of the basic assumptions used to determine the requirements.

To increase flexibility and to allow for the incorporation of new information, a higher level model could be added. In Level 2, energy requirements would still be expressed in terms of DE, but the user would have some flexibility to adjust some factors used in the determination of individual requirements. In the 1989 publication, DE requirements for early lactation are based on assumptions about the amount of milk mares produce (3% of BW) and the amount of DE needed to produce a kilogram of milk (.792). In a Level 2 model, a user could alter these two assumptions. For example, if the user had information suggesting that milk production was higher than 3% of body weight, then the assumptions could be adjusted to the applicable higher value. In a Level 2 model, the user could also make adjustments to the amount of DE required per kilogram of milk. For instance, it is expected that the digestible energy in a high fat, high starch diet is more efficiently converted to net energy than the digestible energy in a high fiber diet. As a result, the amount of DE required when horses consume a high fat, high starch diet would be actually less than when a high fiber diet is consumed.

The concept of a multilevel model is not novel. Nutrient Requirements of Beef Cattle (NRC, 1996) utilizes a two-level model. Level 1 is suggested for use when information on feed composition is limited and when the user is not experienced in using, interpreting, and applying the inputs and results from Level 2. The second level requires a greater understanding of feed ingredients and a greater knowledge of specific animals or management conditions. In the beef cattle scenario, Level 2 was envisioned as having several purposes including being a tool for evaluating feeding programs while accounting for more of the variation in animal performance in specific production settings.

Although any models constructed for horses will probably be much less complex than models constructed for other species, a two-level model will still allow users to fine-tune some requirements if they have the knowledge to do so. Obviously there is a potential downside to allowing user input. Users without sufficient expertise, or with inaccurate information, could make changes that could result in large errors in estimating requirements. These errors could have profound effects on animal well-being. Consequently, it would be essential to design Level 1 as a completely protected model, and Level 2 as a partially protected model. Partial protection could include an alert to the user whenever requirements calculated in Level 2 deviate from the values determined in Level 1 by more than a predetermined amount, perhaps 10 to 20%.

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