17th

PROCEEDINGS OF THE 2010

KENTUCKY EQUINE RESEARCH

NUTRITION CONFERENCE

Feeding and Veterinary Management OF THE SPORT HORSE

APRIL 26-27, 2010
Lexington, KY

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Energetics: Choosing the Appropriate Fuel for the Performance Horse

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INTRODUCTION

When it comes to nutritional requirements, performance horses are in a class of their own. Broodmares need large quantities of high-quality protein and minerals to grow a large healthy foal during gestation and to produce gallons of nutrient-rich milk daily through lactation. Likewise, young horses require plenty of protein and minerals to add hundreds of pounds of muscle and bone during their first year of life. Performance horses must produce one thing--locomotion--and it requires heaps of energy. While they certainly have a requirement for other nutrients, diet formulation for performance horses usually begins and ends with energy.

In the wild, horses survived by grazing relatively poor-quality grasslands. Their digestive system evolved to efficiently utilize this type of diet, but their nutrient requirements were also fairly low. Many of today's performance horses have energy requirements that cannot be met by forage alone. This article will review the best energy sources for performance horses and make recommendations about how to minimize problems related to feeding.

Energy Generation During Exercise

Performance horses perform a wide range of exercise intensities and durations. This may vary from high-speed racing at speeds up to 40 mph (64 km/hr) for short distances, to endurance racing at speeds of 11-15 mph (18-25 km/hr) for 100 miles (160 km), to draft work where horses pull or carry heavy loads for variable amounts of time. The basic driving force behind all of these different types of equine performance is the conversion of chemically bound energy from feed into mechanical energy for muscular movement.

Because horses do not eat continuously while they exercise, feed energy must be stored in the horse's body for later release. There are a number of different storage forms that the horse can utilize, including intramuscular glycogen and triglycerides and extramuscular stores such as adipose tissue and liver glycogen. Many factors determine the proportion of energy derived from each storage form including speed and duration of work, feed, fitness, muscle fiber composition, and age of the horse.

Work capacity depends on the rate at which energy (adenosine triphosphate, or ATP) is supplied to and used by muscles for contraction. The most direct way to form ATP is by the cleavage of creatine phosphate (CP). However, since muscle contains only small amounts of CP and ATP, the supplies are exhausted after a short duration of exercise. Prolonged exercise would not be possible unless there were ways for ATP to be resynthesized at the same rate at which it was used. Two fundamental reactions resynthesize ATP. In the first, oxidative phosphorylation breaks down carbohydrates, fats, and protein into energy (ATP) with the involvement of oxygen. The use of oxygen qualifies this as an aerobic reaction. In the second, glycolysis breaks down glucose or glycogen into lactic acid. This reaction doesn't use oxygen and is considered anaerobic.

Large quantities of energy can be derived from the utilization of intramuscular (triglyceride and glycogen) and extracellular (free fatty acids from adipose and glucose from the liver) fuels. The total amount of fuel stored in a 1,000-lb (450-kg) horse is shown in Table 1.

Table 1. Stored fuels in a 1,000-lb (450-kg) horse.

Fuel	**Tissue**	**Grams**	**Relative Energy**
Triglycerides	muscle	1,400-2,800	1 X
Triglycerides	adipose	20,000-60,000	25 X
Glycogen	muscle	3,000-4,000	1 X
Glycogen	liver	90-220	0.05 X
Glucose	blood	25-50	0.01 X

Muscle Fiber Types

The horse has three basic types of muscle fiber: Type I, IIA, and IIB. These fiber types have different contractile and metabolic characteristics (Table 2). Type I fibers are slow-contracting fibers, while types IIA and IIB are fast-contracting. The type I and IIA fibers have a high oxidative capacity and can thus utilize fuels aerobically, while type IIB fibers have a low aerobic capacity and tend to depend on anaerobic glycolysis for energy generation. All three fiber types are very high in glycogen, while only type I and IIA have triglyceride storage.

Table 2. Metabolic characteristics of different muscle fiber types.

Classification	**ST**	**Type I FTH (II A)**	**Type II FT (II B)**
Speed of contraction	slow	fast	fast
Max. tension developed	low	high	high
Oxidative capacity	high	intermediate to high	low
Capillary density	high	intermediate	low
Lipid content	high	intermediate	low
Glycogen content	intermediate	high	high
Fatigability	low	intermediate	high

Substrate Utilization During Exercise

The amount of ATP used by a muscle depends directly on how fast it is contracting. While walking, the muscles contract very slowly and expend relatively small amounts of ATP. During this type of exercise, type I fibers are primarily recruited and energy generation is entirely aerobic. At this speed, the muscle burns predominantly fat. Fat stores are plentiful, and they can be mobilized and metabolized fast enough to regenerate the amount of ATP that is used at a walk. As speed increases from a walk to a trot to a canter, type I fibers alone are no longer capable of contracting rapidly enough to propel the horse. At this point, type IIA fibers are also recruited. These fibers are also aerobic, but they use a combination of glycogen and fat for energy generation. Glycogen (or glucose) can be metabolized aerobically twice as fast as fat for ATP generation, and as speed increases, fat becomes simply too slow a fuel for energy generation. As the horse increases speed to a fast gallop, type IIB fibers are recruited and energy generation no longer remains purely aerobic. Anaerobic glycolysis is the fastest metabolic pathway available to generate ATP, and the horse must depend heavily on this to maintain high rates of speed. Anaerobic glycolysis, however, results in lactic acid accumulation, and fatigue soon develops as the pH in the muscle begins to fall.

The endurance horse typically travels at speeds that can be maintained almost entirely through aerobic energy generation. Only during hill climbing and for short intervals is the horse's ATP demand too great for aerobic regeneration. Fatigue in endurance horses is much more likely to result from glycogen depletion than from lactic acid accumulation.

Racehorses, eventers, and many of the western performance horses exercise at much higher intensities. These horses depend heavily on anaerobic glycolysis for energy generation, and fatigue is most likely to result from lactic acid accumulation rather than glycogen depletion.

Substrate utilization in the horse can be investigated by using biopsy techniques of both the muscle and the liver. These biopsies are safe and can be taken repeatedly to determine how much muscle glycogen is used at different intensities of work. In addition, substances in the blood and respiratory gases can be used to paint a metabolic picture of substrate utilization during various intensities of exercise. The middle gluteal muscle is the most convenient muscle to biopsy when studying intramuscular substrate utilization. This muscle typically contains between 500 and 700 millimoles (mmol) of glycogen per kilogram (kg) of dry weight. During endurance exercise, horses will typically use muscle glycogen at a rate from 0.5 to 1.5 mmol/kg/min. The remainder of the energy generated at this rate of speed comes from fat oxidation. As speed increases, muscle glycogen utilization increases. At a speed of around 650 meters/min (a 2:25 mile), ATP production can no longer be completely satisfied by aerobic pathways. At this point, anaerobic pathways become an important source of energy. In shifting to this type of energy production, the use of glycogen and the accumulation of lactic acid increase exponentially.

Figure 1. Muscle glycogen used per minute in relation to speed.

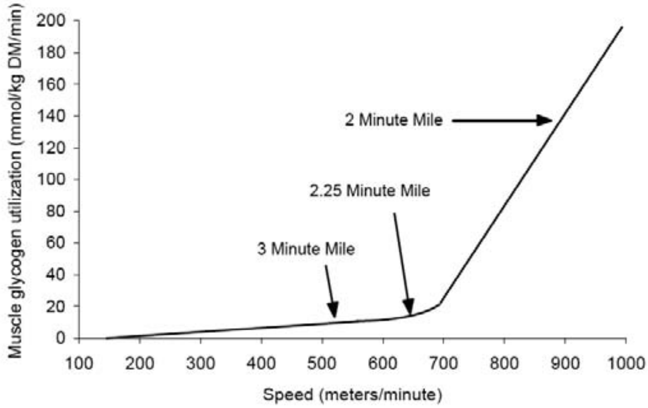

Figure 1 shows the amount of muscle glycogen used per minute in relation to speed. These data are compiled from a number of different breeds. Notice that when the horse runs at speeds of less than 650 meters/min, very little glycogen is used. However, when speed is increased, the horse crosses what is known as its "anaerobic threshold," and the use of muscle glycogen increases dramatically.

The basic reason for this increase is that anaerobic glycogen utilization is 12 times less efficient than aerobic glycogen utilization. When glycogen is metabolized aerobically, 36 ATPs are produced, but when glycogen is metabolized anaerobically, only 3 ATPs are produced (2 molecules of lactate are also produced).

Dietary Energy Considerations

Dietary energy is usually expressed in terms of megacalories (Mcal) or megajoules (MJ) of digestible energy. Digestible energy (DE) refers to the amount of energy in the diet that is absorbed by the horse, and a horse's DE requirement is calculated based on the maintenance DE requirement plus the additional energy expended during exercise. Basically, DE can be provided by three different dietary energy sources: carbohydrates, fat, and protein.

Carbohydrates in horse feed

The carbohydrates in equine feeds can be categorized by either their function in the plant or by the way they are digested and utilized by the horse. From a plant perspective, carbohydrates fall into three categories: (1) simple sugars active in plant intermediary metabolism; (2) storage compounds such as sucrose, starch, and fructans; and (3) structural carbohydrates such as pectin, cellulose, and hemicellulose. For the horse, it is more appropriate to classify carbohydrates by where and how quickly they are digested and absorbed. Carbohydrates can be digested and/or absorbed as monosaccharides (primarily glucose and fructose) in the small intestine, or they can be fermented in the large intestine to produce volatile fatty acids or lactic acid. The rate of fermentation and types of end products produced are quite variable and can have significant effects on the health and well-being of the horse.

A physiologically relevant system to categorize carbohydrates in equine diets would be: (1) A hydrolyzable group (CHO-H) measured by direct analysis that yields sugars (mainly glucose) for metabolism. This includes simple sugars, sucrose, and some starches that are readily digested in the small intestine and produce fluctuations in blood glucose post-feeding. (2) A rapidly fermentable group (CHO-FR) that yields primarily lactate and propionate. This group includes starches that escape digestion in the small intestine as well as galactans, fructans, gums, mucilages, and pectin. (3) A slowly fermentable group (CHO-FS) that yields mostly acetate and butyrate. This group includes the compounds captured in neutral detergent fiber (NDF) such as cellulose, hemicellulose, and lignocellulose.

Hydrolyzable carbohydrates. Hydrolyzable carbohydrates (CHOH) are an important component of equine diets, particularly for the performance horse, in which blood glucose serves as a major substrate for muscle glycogen synthesis. Too much blood glucose, however, may contribute to or aggravate certain problems in horses such as recurrent equine rhabdomyolysis (RER) and polysaccharide storage myopathy (PSSM). It may also adversely affect behavior in particular individuals.

The quantity of blood glucose produced in response to a meal is a useful measure of a feed's CHO-H content. Table 3 contains the glycemic index of several equine feeds measured at Kentucky Equine Research (KER). Glycemic index characterizes the rate of carbohydrate absorption after a meal and is defined as the area under the glucose response curve after consumption of a measured amount of a test feed divided by the area under the curve after consumption of a reference meal, in this case oats.

Table 3. Glycemic index (GI) of equine feeds and forages.

Feed	**Glycemic Index**
Sweet feed	129
Whole oats	100
Equine Senior®	100
Beet pulp + molasses	94
Cracked corn	90
Beet pulp (unrinsed)	72
Orchardgrass hay	49
Rice bran	47
Ryegrass hay	47
Alfalfa hay	46
IR pellet™ + orchardgrass hay	34
Rinsed beet pulp	34
Bluestem hay	23

The major CHO-H fraction in performance rations is starch, a carbohydrate composed of a large number of glucose molecules. It is the primary component of cereal grains, making up 45 to 70% of the grain's dry matter. Of the grains commonly fed to horses, corn has the highest starch content. Starch is a versatile energy source for the performance horse. Horses break down starch into glucose units in the small intestine, where it is absorbed into the blood. Once in the blood, these glucose units can be used for a number of different purposes: (1) they can be oxidized directly to produce ATP; and (2) blood glucose can be used to make muscle glycogen, liver glycogen, or body fat.

Muscle glycogen is an important fuel for energy generation during exercise. In addition, glycogen is stored in the liver where it is available for the production and release of glucose into the blood during exercise. Maintaining blood glucose levels during exercise is of prime importance since glucose is the only fuel that is available to the central nervous system. Hypoglycemia is another potential cause of fatigue in exercised horses.

Starch is the dietary energy source of choice for glycogen synthesis because starch digestion results in a direct rise in blood glucose and insulin, two of the most important factors involved in glycogen synthesis.

Rapidly fermentable carbohydrates. Two interesting alternative energy sources for performance horses are beet pulp and soy hulls. Both contain a high percentage of rapidly fermentable carbohydrates (CHO-FR), primarily pectin, which is an important gluconeogenic substrate for the horse. Rapid fermentation of undigested starch from cereals, however, can also produce lactic acid, which may lead to a cascade of events culminating in laminitis, and are the most likely compounds contributing to lactic acidosis in the hindgut. When large grain meals are fed to horses, a portion of the starch may escape digestion in the small intestine and rapidly ferment in the cecum and colon. Volatile fatty acid (VFA) and lactic acid production increases, causing a significant decrease in pH. Lactic acid is a stronger acid than VFA and may cause irritation or damage to the intestinal mucosa. In severe cases, lactate may contribute between 50 and 90% of the total acids in the hindgut. Furthermore, lactic acid accumulation increases the permeability of the large intestinal mucosa to toxins and larger molecules that have been implicated in the development of laminitis.

A downward shift in pH provides an unfavorable environment for many of the fiber-fermenting microorganisms that inhabit the hindgut. In particular, bacteria such as *Ruminococcus albus* and *Fibrobacter succinogenes* are sensitive to precipitous decreases in pH. For optimal performance, these bacteria favor an environment with a pH between 6.5 and 7.0. When pH drops below 6.0, fiber-digesting bacteria become less efficient and begin to die off. In contrast to fiber-digesting bacteria, lactate-producing and lactate-utilizing bacteria thrive in an environment with a low pH. Certain microorganisms such as *Streptococcus bovis* actually shift their metabolism and produce lactic acid rather than VFA when exposed to acidic conditions, serving only to compound the problem. Changes in the pH of the hindgut due to alterations in the microbial populations and acid profiles may result in hindgut acidosis (HGA).

Horses with HGA may develop anorexia, colic, or stereotypical behaviors such as wood chewing and stall weaving. Furthermore, long-term exposure to pHs below 5.8 will begin to have deleterious effects on the epithelial lining of the colonic and cecal walls, which in turn may affect absorptive capacity.

Rumen acidosis is a common problem in dairy cattle fed high grain diets. Sodium bicarbonate is often added to a cow's ration as a buffer to attenuate drops in rumen pH that decrease feed intake and milk production. Sodium bicarbonate has also been shown to be effective in treating HGA in horses when it is infused directly into the cecum via cecal fistula. Unfortunately, feeding raw sodium bicarbonate to horses is ineffective because of the anatomy of their gastrointestinal tract. Ideally, the sodium bicarbonate should be protected so that it is delivered to the hindgut intact. Kentucky Equine Research (KER), in conjunction with Balchem Corporation, has recently developed an encapsulated sodium bicarbonate (EquiShure®) that survives transit through the stomach and small intestine of the horse.

KER conducted a series of studies to evaluate the effect of EquiShure® on HGA in horses fed high levels of starch or fructans. In one study, six Thoroughbreds in training were fed a basal diet of unfortified sweet feed, timothy grass hay, and 50 g of loose salt per day. Grain intakes ranged from 4 to 6 kg per day. Horses were split into two groups and assigned to one of two treatments. The treatments were 168 g/day of EquiShure® or the basal diet (control group). Horses switched treatments for period 2. Both the hay and grain portions of the diet were split into two equal feedings. One-half of the EquiShure® (84 g) was added to each grain meal.

Fecal samples were taken at 2-hour intervals for an 8-hour period on day 15 of each period and analyzed for volatile fatty acids (VFAs), pH, and L- and D-lactate concentration. Fecal pH in the control group decreased significantly from baseline by 6 hours post-feeding (Figure 2). Fecal pH in the EquiShure® group did not exhibit any significant fluctuations during the 8-hour sampling period. Fecal L-lactate and D-lactate were significantly higher ($P<0.05$) post feeding in the control group compared to the EquiShure® group. Fecal VFAs were significantly higher ($P<0.05$) in the EquiShure®-supplemented group, suggesting a more favorable environment for fiber-fermenting bacteria. EquiShure® was effective in attenuating the HGA that resulted from high grain intakes in exercised Thoroughbreds.

Slowly fermentable carbohydrates. Slowly fermentable carbohydrates (CHO-FS) from the plant cell wall are absolutely essential to maintain a healthy microbial environment in the horse. Since proper gut function is essential to the health and well-being of the horse, fiber-rich forage should be considered the foundation of a performance horse's feeding program. Performance horses should be fed 15-20 lb (7-9 kg) per day of clean grass hay such as timothy or oaten hay. Two to four lb (1-2 kg) per day of alfalfa hay may also be offered. This level of hay intake will meet the performance horse's maintenance DE requirement and help protect against gastric ulcers and colic.

Carbohydrate Analysis

Carbohydrates in horse feeds have traditionally been estimated by measuring cell wall components as NDF (neutral detergent fiber) and calculating the remaining carbohydrate by difference as nonfiber carbohydrate (NFC), where NFC = 100 - water - protein - fat - ash - NDF. More recently, laboratories have provided a direct analysis of additional carbohydrates in equine feeds.

Table 4 contains the chemical composition of several common equine feedstuffs as analyzed by Equi-analytical Laboratories in Ithaca, NY. In addition to NDF and the calculated values of NFC, Table 4 contains measured levels of water-soluble sugars (WSS) and starch.

Table 4. Carbohydrate content of some common equine feeds.

	Oats	Corn	Beet pulp	Soy hulls	Legume hay	Grass hay
WSS %	3.9	3.5	10.6	3.6	9.0	10.7
Starch %	44.3	70.5	1.3	1.7	2.4	2.8
NSC %	50.7	73.1	12.1	5.3	11.4	13.3
NFC %	50.9	76.4	44.4	19.8	30.8	19.5
NDF %	27.9	9.8	41.9	61.7	38.5	63.8

The sum of WSS and starch is considered the nonstructural carbohydrate (NSC). WSS in cereal grains and byproducts such as beet pulp are composed of simple sugars that produce a pronounced glycemic response and fit into the CHO-H category. By contrast, much of the WSS in temperate grasses are actually fructans, which should be included in the CHO-FR fraction. Therefore, they would have little effect on glycemic response but may contribute to the development of hindgut acidosis and laminitis. Starch is the predominant carbohydrate fraction in cereal grains.

Although all starch is made up of glucose chains, how the starch molecule is constructed varies in different types of grain. These differences in the architecture of individual starches have a large impact on how well they are digested in the horse's small intestine. Of the grains most commonly fed to horses, oats contain the most digestible form of starch, followed by sorghum, corn, and barley. Processing can have a huge effect on prececal digestibility, particularly in corn. In a KER study, steam flaking corn caused a 48% increase in glycemic response compared to coarse cracking. NSC is a mixture of CHO-H and CHO-FR fractions. NSC tends to be higher in CHO-H in processed cereal grains and mixes but may be high in CHO-FR in certain unprocessed cereals or high-fructan forages.

NFC represents an even more mixed group of carbohydrates because in addition to the compounds found in NSC, they may also contain significant quantities of pectin and other fermentable compounds not captured in NDF. For instance, beet pulp contains only 12.1% NSC but 44.4% NFC. At present, there is no satisfactory, commercially available analytical method to segment carbohydrates into categories that are physiologically meaningful for the horse.

Fat

Fat is an attractive alternative energy source for performance horse rations, supplying a large number of calories in a concentrated form. Even though horses do not consume large quantities of fat in the wild, they do a very good job of digesting fats, particularly vegetable oils. Most vegetable oils contain long-chain (16-18 carbon) unsaturated fats. These fats are liquid at room temperature and are used extensively as human foods for cooking and salad oils. A notable exception is coconut oil, which contains a high level of medium-chain (12 carbon) saturated fats. Animal fats, on the other hand, tend to be more saturated than vegetable oils and often are solid at room temperature. Horses typically digest vegetable oils better than animal fat. Once adapted, horses will digest over 90% of the vegetable oil in a ration, even when fed at levels as high as

500-600 ml per day. High levels of oil intake should be reached slowly, however, since some horses may develop loose, greasy feces when switched to a high oil diet too quickly.

The energy density of vegetable oils is quite high, averaging about 2.25 times that of starch. Vegetable oil has about 2.5 times as much digestible energy (DE) as corn and 3.0 times as much DE as oats. Because of its high digestibility, fat is a very safe energy source. Even if some oil escapes digestion in the small intestine, it will not cause major disruptions of fermentation in the hindgut because bacteria cannot ferment long-chain oils.

The level of oil included in a ration will depend primarily on what the horse is doing. Horses that are lightly ridden or used predominantly for show require less oil in their rations. As little as 70-80 ml of oil per day will have a beneficial effect on the horse's hair coat, but will only provide about 2.5% of a lightly exercised horse's DE requirement. Higher levels of oil intake are needed for more strenuous exercise. A horse in heavy training should receive around 400 grams (~450 ml) of vegetable oil per day. This is equal to around 10% of its total daily DE intake and around 18-20% of the DE supplied by the concentrate. Five or six kg of a 10% fat grain mix would supply this level of supplemental vegetable oil.

During low- to moderate-intensity exercise, horses supply a large proportion of the energy used for muscle contraction with fat oxidation. Free fatty acids are mobilized from adipose tissue and delivered to the working muscle for oxidation. The amount of fat burned by muscle is directly proportional to the concentration of FFA in the blood. Long-term fat supplementation in combination with appropriate training will result in increased mobilization of free fatty acids (FFA) and increased speed of mobilization along with an increased speed of uptake of FFA into muscle. Additionally, feeding fat has a glucose- and glycogen-sparing effect that may delay fatigue during endurance exercise. A recent study conducted by KER with Arabian horses demonstrated this sparing effect. After 10 weeks of fat supplementation (10% fat), the horses used 30% less glucose and muscle glycogen during an endurance exercise test.

Researchers have recently focused their attention on two distinct families of fatty acids: the omega-3 family and the omega-6 family. The omega-3 family stems from alpha-linolenic acid (ALA), while the omega-6 family originates from linoleic acid (LA). ALA and LA are considered "essential fatty acids" because they are instrumental in the life cycle, yet they cannot be manufactured in the body and must be obtained from dietary sources. Significant members of the omega-3 family are eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA).

The advantages of supplementing equine athletes with omega-3 fatty acids are coming to light. A reduction in joint inflammation in older arthritic horses was reported in horses supplemented with omega-3 fatty acids. Horses fed the supplement had lower synovial fluid white blood cell counts than those in the control group, indicating a lower level of inflammation.

Supplementation with omega-3 has been hypothesized to reduce exercise-induced pulmonary hemorrhage (EIPH) in horses. Researchers have reported modulation of a decrease in erythrocyte membrane fluidity during exercise in horses fed a diet enriched with DHA and EPA. Preliminary results from a study in 10 Thoroughbred horses at Kansas State University showed a reduction of EIPH after 83 and 145 days on a diet enriched with both DHA and EPA, but not with DHA alone.

The composition of fatty acids differs considerably in oils added to horse diets (Table 5). Linoleic acid (LA) is greatest in safflower, corn, soybean, and sunflower oils, respectively, and is lowest in fish oil (menhaden), while linseed oil is rich in alpha-linolenic acid (ALA). Fish oil has achieved popularity as an equine feed component, due in part to its concentration of the omega-3 fatty acids DHA and EPA.

Table 5. Fatty acid composition of selected oils commonly used in horse diets.

Selected fatty acids (% of total fatty acids)				Omega-3 to omega-6 ratio
	Linoleic acid (LA)[1]	Alpha-linolenic acid (ALA)[2]	DHA and EPA[2]	
Canola oil	22.1%	11.1%	-	Moderate
Corn oil	58.0%	0.7%	-	Low
Linseed oil	12.7%	53.3%	-	High
Safflower oil	74.1%	0.4%	-	Low
Soybean oil	51.0%	6.8%	-	Moderate
Sunflower oil	39.8%	0.2%	-	Low
Fish (menhaden) oil	2.0%	1.5%	26.4%	High

[1]*Omega-6 fatty acids.*
[2]*Omega-3 fatty acids.*

Protein

If the protein content of a performance horse's ration exceeds its requirement, the extra protein can be used as a source of energy. The amino acids from this extra protein are broken down by the liver, and the nitrogen from the protein is excreted as ammonia. The carbon "skeletons" that are left can be oxidized to produce ATP or used to make glucose or fat. Excessive protein intake should be avoided in the exercised horse for a number of reasons: (1) water requirements increase with increased protein intake; (2) urea levels increase in the blood leading to greater urea excretion into the gut, which may increase the risk of intestinal disturbances such as enterotoxemia; and (3) blood ammonia increases causing a number of problems such as nerve irritability and disturbances in carbohydrate metabolism. Increased ammonia excretion in the urine may also lead to respiratory problems because of ammonia buildup in the stall.

Conclusion

The rations of performance horses should include a mixture of energy sources. In this regard, moderation is the key. Excessive amounts of starch should be avoided as this may lead to colic, founder, or tying-up in horses. Excessive protein may lead to problems associated with ammonia production. Fiber must be included in the diet to maintain proper hindgut function. Including the correct mixture of these energy sources in the performance horse's ration should reduce problems associated with feeding and allow the horse to utilize energy-generating substrates most efficiently during exercise.