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NUTRITIONAL MANAGEMENT OF MARES—THE FOUNDATION OF A STRONG SKELETON

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Introduction

The impact of a broodmare feeding program can be substantial on the skeletal development of the foal and the equine athlete. Among domestic animals, horses have the shortest period between parturition and rebreeding, and ideally the mare will be both lactating and pregnant simultaneously. Most horsemen have an appreciation for the obvious things that feeding affects such as fertility, milk production by mares, and the health of their foals. In recent years the importance of good nutrition during pregnancy has become more apparent. The goal of a feeding program for mares is to complement other facets of management so that total efficiency of the broodmare band is not compromised by nutrition and wastage of foals is minimized. One of the major causes of wastage is skeletal disease, and one of the most important periods for sound growth is the time prior to weaning when the foal is still nursing the mare. Studies of the incidence of osteochondritis dissecans (OCD) have shown that the disorder is very dynamic during the early months of life and that the highest recorded incidence occurs at 5 months of age. Many foals are still not weaned at this age and are reliant on nutrition from mare's milk, pasture and other forages, and concentrates from the mare's feed bin or creep feeder. Unfortunately, the pressures of the breeding season mean that many foals get more scrutiny and individual attention at or after weaning; by then, however, it may be too late.

Mares should be divided into four classes when considering their nutritional needs: (1) the maiden mare; (2) the barren and early pregnant non-lactating mare; (3) the mare in the last third of pregnancy; and (4) the lactating mare (and possibly pregnant as well).

Each of these classes of mares needs the same nutrients in the diet, but at different levels of intake, as nutrient requirements are based on the physiological state. In addition, foals within a breed vary in their metabolism and growth rate so they need to be fed differently. The contrast between the nutrient needs and feeding practices required by Thoroughbred mares and warmblood mares is striking. This paper will cover the important nutrient needs of different classes of mares and the feeding practices required in different management situations to achieve optimal nutrition for skeletal development.

Nutrient Needs of Mares

ENERGY AND PROTEIN

The requirements for energy and protein during pregnancy do not increase substantially until the last trimester of pregnancy, when 75% of the fetal growth occurs (Table 1). There are very few studies to verify energy and protein requirements for mares, and more work is needed to clarify differences in requirements between breeds. In other species, maternal malnutrition has been shown to lead to long-term changes in metabolic processes in the offspring. Could the performance potential of an equine athlete be influenced by intrauterine growth retardation that results from maternal malnutrition, disease, or reduced supply of nutrients to the fetus arising from placental or umbilical abnormalities? This topic has been covered in an excellent review article by Rossdale and Ousey (2002).

Table 1. KER nutrient requirements of the 500-kg light horse broodmare[1].

Nutrient	*Early pregnancy*	*Late pregnancy*	*% change*	*Early lactation*	*% change*	*Late lactation*
DE (MJ)	68	89	29	118	33	102
Protein (g)	697	938	35	1414	51	1217
Lysine (g)	24	33	38	50	52	43
Calcium (g)	30	47	57	61	30	47
Phosphorus (g)	20	31	55	41	32	31
Magnesium (g)	10	12	20	15	25	12
Zinc (mg)	337	450	34	600	33	500
Copper (mg)	112	150	34	150	0	125
Manganese (mg)	337	450	34	600	33	500
Selenium (mg)	1.9	2.2	16	3	36	2.5
Iodine (mg)	1.5	1.75	17	2.25	29	1.9
Vitamin A (IU)	37500	43750	17	75000	71	62500
Vitamin E (IU)	375	700	87	750	7	625

[1]Light horses include Thoroughbreds, Standardbreds, Arabians, Quarter Horses, and similar breeds. Many mares are heavier than 500 kg, but this weight is used for comparison purposes.

Kentucky Equine Research (KER) has developed estimated nutrient requirements for warmbloods that take into account differences in metabolism and growth rate between light horses and warmbloods (Table 2). This table shows that warmblood mares need less energy and protein and more minerals than light horse mares of the same weight.

Table 2. Comparison of nutrient requirements of 500-kg Thoroughbred (TB) and 700-kg warmblood (WB) mares during late pregnancy and early lactation.

	TB Late pregnancy	*WB Late pregnancy*	*% difference*	*TB Early lactation*	*WB Early lactation*	*% Difference*
Weight (kg)	575	800	40	500	700	40
DE (MJ)	89	97	9	118	112	-5
Protein (g)	938	1152	23	1414	1506	7
Lysine (g)	33	40	21	50	53	6
Calcium (g)	47	66	40	61	85	39
Phosphorus (g)	31	44	42	41	57	39
Magnesium (g)	12	17	42	15	21	40
Zinc (g)	450	630	40	600	840	40
Copper (mg)	150	210	40	150	210	40
Manganese (mg)	450	630	40	600	840	40
Selenium (mg)	2.2	3.1	41	2	4.2	40
Iodine (mg)	1.75	2.45	40	2.25	3.15	40
Vitamin A (IU)	43750	61250	40	75000	105000	40
Vitamin E (IU)	700	980	40	750	1050	40

It is thought that during energy or protein deprivation pregnant and lactating mares will draw upon stored reserves to maintain intrauterine growth of a fetus and milk production. During pregnancy, fetal growth is very slow during the early months. By the end of the seventh month of pregnancy, the fetus has only deposited 10% of the protein it will contain at birth. In the last four months of pregnancy, the fetus will deposit about 8 kg of protein as it grows to a birth weight of 50 kg (protein deposited and birth weight will vary depending on breed). During the last month of pregnancy alone, the fetus will deposit over 2.5 kg of protein into its body. Mares produce large quantities of milk and this dramatically increases demands for protein and energy. Milk production is estimated at between 3 and 4% of body weight during the first 2 months of lactation, and this declines to 2% of body weight after 5 months. Milk is 20-25% protein on a dry matter basis.

Gill et al. (1985) restricted mares to 70% of protein needs during pregnancy and lactation and found that birth weights were not affected, but growth rate of the foal to 90 days was reduced in the restricted group compared to mares fed normal diets during both pregnancy and lactation or those restricted during pregnancy but not lactation. These diets were not isocaloric. This effect of protein deprivation on the growth rate of foals was presumed to have occurred via an effect on milk production. The quality of protein supplied to the lactating mare may influence milk production and growth rate. Glade and Luba (1990) added soybean meal to the diet of Thoroughbred mares being fed a high-protein concentrate 2 weeks prior to and 7 weeks after foaling. The addition of 500 g of soybean meal prior to foaling and 750 g after foaling was matched by a reduction in concentrate intake so that the DE intake remained the same in both groups. The crude protein content of milk was significantly increased in the first 5 weeks of lactation, and the foals of soybean-supplemented mares grew 10% taller in the first 7 weeks of life. The control group of mares in this study were fed a 16% (as fed) crude protein concentrate and were supplied with crude protein and lysine in excess of National Research Council (NRC) requirements both before and after foaling. However, several studies have also shown that variations in protein and amino acid intake had no impact on the composition of mare's milk.

The impact of protein and energy restriction may depend upon the reserves the mare has to draw on. Pagan et al. (1984) found that there was no difference in the growth rate of pony foals on mares that were fed either 70% or 130% of their energy and protein requirements. Mares either lost or gained weight, but foal growth rate did not change. However, when mares were in poor body condition (a body condition score of 2) and had fewer reserves to draw on for the energy and protein required for milk production, growth rate of the foal was reduced. The same group of researchers found that feeding excess energy to pony mares led to reduced fat and protein content in the milk, which might reduce growth rate. Doreau and Boulet (1987) found that thin mares had lower milk production than fat mares.

Adding 5% fat to the diet of lactating mares led to an increase in milk energy production (Davison et al., 1991). Hoffman et al. (1996) found that mares fed a high-fat, high-fiber concentrate prior to and after foaling had higher levels of linoleic acid in their milk than mares fed a high-starch, high-sugar concentrate. This increased linoleic acid content may protect foals against the development of gastric ulcers, and the mares fed the high-fat, high-fiber diet also had higher immunoglobulin levels in their colostrum, which may improve protection against disease. Doreau et al. (1992) found that increasing the proportion of concentrates in the diet of the lactating mare from 5% to 50% led to an increased milk yield and lactose content, but it was more dilute with a lower protein concentration. This change led mares on the high-grain diet to gain weight but did not affect the growth of the foals.

Prolactin is a hormone that is important in parturition and milk secretion in the mare. Recent work has shown that energy restriction and low body condition can reduce prolactin secretion, and this could be an important consideration in lactating mares. Dry mares kept in poor to moderate condition produced less prolactin than mares kept in fat condition (Gentry et al., 2002), and geldings kept on a high-for-age diet that only supplied 70% of energy needs produced lower prolactin levels following stimulation with thyroid releasing hormone (Powell et al., 2003).

MINERALS

The requirements of horses for calcium, phosphorus, and magnesium were reviewed by Hintz at the 2000 KER Nutrition Conference. They are important minerals in the diet of pregnant and lactating mares because they are needed to supply the rapid growth of bone in the fetus in late pregnancy and in the foal prior to weaning. By 6 months of age, the foal has reached 85% of its height and has 68% of its bone mineral content. Many foals would not be weaned by this time, and if the mare were not being given supplementary feed, all of these minerals would have been supplied by the placental circulation, milk, and grass.

Martin et al. (1996) measured changes in serum concentrations of calcium (Ca) and parathyroid hormones in mares fed diets containing calcium concentrations below (0.35%) and above (0.55%) the NRC requirement of 0.45%. They found less extreme variations of serum total calcium, ionized calcium, and parathyroid hormone in the mares that were fed 0.55% calcium than in mares fed 0.35% calcium. They suggested that the optimal concentration of dietary calcium for prepartum mares was closer to 0.55% than 0.35%. Glade (1993) estimated metacarpal breaking strength (MBS) by transmission ultrasound of mares during the last 12 weeks of gestation and for 40 weeks after foaling. MBS increased during the last 6-10 weeks of gestation in mares fed amounts of calcium similar to NRC recommendations, but mares fed 20% less calcium than NRC recommendations did not have an increase in MBS. Importantly, foals of the mares fed the lower level of calcium had thinner mid-cannon circumference and mechanically weaker bones at birth than foals of control mares and the differences persisted for 40 weeks. These indicate that the pregnant mare probably needs more calcium intake than the NRC recommendation, but the optimal level has not been established.

It was estimated that mare's milk contains about 1.2 g of Ca/kg of fluid milk during early lactation (first three months) and 0.8 g of Ca/kg of fluid milk during late lactation (Schryver et al., 1986; Grace, 1999), so lactating mares need nearly three times the calcium intake of dry mares. Wide variation in calcium intake by mares has been shown to have no effect on concentration in milk in a number of studies (Lewis, 1995). However, Lewis (1995) cited a study in which milk calcium concentration was 40% lower in mares receiving 33% of dietary calcium needs, but levels were not increased above normal values in mares getting 250% of their daily requirement. Glade (1993) reported that mares fed the NRC recommended levels of calcium gradually lost bone density during the first 12 weeks of lactation, but density started increasing at that time and was fully restored at 24 weeks post-parturition. Mares fed 20% less calcium than recommended, however, had not recovered bone density at 40 weeks after parturition even though the foals were weaned at 20 weeks.

Numerous studies have examined the impact of low dietary cation-anion balance (DCAB) on mineral excretion, and it has been found that low DCAB diets lead to increased calcium excretion (Baker et al., 1993). However, a number of studies on this topic have found that horses can compensate for increased calcium losses by increasing absorption, so that calcium balance is not affected. The most likely cause of a low DCAB diet is a high-grain, low-forage diet, and if this diet is not supplied with adequate supplementary calcium, deficiencies may occur. Another factor to consider is teeth. Correction of molar abnormalities in late pregnant mares was associated with significant increases in digestion and retention of calcium, phosphorus, and magnesium (Gatta et al., 2001).

Phosphorus (P) requirements also increase in late pregnancy and lactation in line with calcium. Donoghue et al. (1990) reported that phosphorus deficiencies were quite common in late pregnancy, while calcium deficiencies occurred in lactation. The phosphorus deposition in the fetus was estimated to be 9.4 g/day for a 500-kg mare during the last three months of gestation based on the body composition data from Dr. Helmut Meyer's laboratory (Drepper et al., 1992). Thus a 500-kg mare would require about 31g of P/day. The phosphorus content of liquid milk in early lactation was 0.75 g/kg and decreased to 0.50 g/kg during late lactation (NRC, 1989). This leads to a 30% increase in phosphorus needs in early lactation. Data from digestion studies at KER have shown that phosphorus digestibility is unaffected by calcium content, but calcium to phosphorus ratio was negatively correlated with fiber content in the diet (Pagan, 1998).

As with calcium and phosphorus, body composition data from the laboratory of Meyer (Drepper et al., 1982) were utilized to estimate magnesium (Mg) requirements of mares. Deposition of magnesium was calculated to be 0.3 mg/kg of body weight of the mare, and it was figured that a 500-kg late pregnant mare would need about 12 g of Mg/day. It was estimated that the magnesium concentration of milk averages 90 mg/kg during early lactation and a 500-kg mare would need about 15 g of magnesium during early lactation. It is possible that nutritionists should be concerned about the calcium to magnesium ratio in the diet of mares, as well as young horses, but there are no data to validate any suggested ratios. Data from digestion studies conducted at the KER laboratory have shown a positive correlation between calcium content and magnesium digestibility and a negative correlation with phosphorus content (Pagan, 1998).

Silicon is a mineral that does not receive much attention. It has an important role in bone calcification and is present in high concentrations in active growth areas of bone. Work at Texas A&M University on supplementation of sodium zeolite A (a source of silicon) to weanlings and yearlings showed that plasma silicon and radiographic bone density were increased (Frey et al., 1992). Would the young growing horse benefit if silicon were fed to the mare during pregnancy or lactation?

TRACE MINERALS

Copper (Cu) is essential for proper synthesis and maintenance of elastic connective tissue and detoxification of superoxide. Copper has received a great deal of attention since the last publication of the NRC because of its suggested role in the pathogenesis of developmental orthopedic disease (DOD). The 1989 NRC estimated that all classes of horses require 10 mg Cu/kg of dry diet. This appears accurate for horses at maintenance but other work suggests that the requirements of copper for young growing horses and broodmares are considerably higher, especially in certain breeds.

New Zealand researchers (Pearce et al., 1998a) studied the effect of copper supplementation on the incidence of DOD in Thoroughbred foals. Pregnant Thoroughbred mares were divided into either copper-supplemented or control groups. Live foals born to each group of mares were also divided into copper-supplemented or control groups. The four treatment groups were: (1) mares supplemented with copper, but their foals were not supplemented; (2) both mares and foals were supplemented with copper; (3) mares were not supplemented, but their foals received supplementation; (4) neither mares nor foals received supplementation.

Supplemented mares received 0.5 mg Cu/kg body weight daily (~250 mg), while copper-supplemented foals received 0.2 mg Cu/kg body weight from 21-49 days of age and 0.5 mg Cu/kg body weight (~100 mg) from 50 days to 150 days. Mares were supplemented for the final 13 to 25 weeks of gestation, and all mares and foals received concurrent selenium and zinc supplementation. At 150 days of age, the foals were sacrificed, and an exhaustive postmortem examination was performed. The number of articular and physeal cartilage lesions was noted for each treatment group along with a physitis score that was determined from radiographs of the distal metatarsus.

Copper supplementation of mares was associated with a significant reduction in the radiographic physitis scores of the foals at 150 days of age. Foals from mares that received no supplementation had a mean physitis score of 6, while foals out of supplemented mares had a mean score of 3.7. A lower score indicates less physitis. When only foals (but not mares) were supplemented with copper, no significant effect on physitis scores was noted. There was a significantly lower incidence of articular cartilage lesions in foals from mares supplemented with copper. However, no significant effects on lesions occurred in foals supplemented with copper.

Two North American dose-response studies examining the effect of increased dietary copper intakes on bone and cartilage abnormalities (Knight et al., 1990; Hurtig et al., 1993) found that the incidence of DOD was decreased by increasing the copper content of the diet above NRC recommendations. In Knight's study, mares were fed 32 ppm compared to 13 ppm. Because both mares and their foals received copper supplementation, it is difficult to determine whether the effect resulted from supplementation of the mare or the foal. New Zealand research (Pearce et al., 1998a,b) would suggest that supplementation of the pregnant mare is more important than supplementation of the foal. Oral copper supplementation of mares in late gestation altered the copper balance in these horses and resulted in an increase in the foal's liver copper stores at birth. Increased liver copper stores of the neonate may be important for ensuring healthy development of the skeleton during the period of maximum postnatal growth. Van Weeren et al. (2003) examined the copper status of foals at birth and the incidence of radiographic signs of OCD in warmblood foals genetically prone to OCD. The foals were evaluated at 5 months and 11 months of age. Radiographic score was not related to liver copper concentration at birth, but foals with high liver copper levels had improvements in the severity of OCD changes in the stifle from 5 months to 11 months. Foals with low liver copper levels at birth had more severe signs of OCD at 11 months than 5 months, indicating that copper is perhaps less involved as a cause of OCD and more important in repair of lesions.

These studies certainly provide proof that copper supplementation of mares and their foals can play an important role in skeletal development. Copper is not, however, the only factor involved in the pathogenesis of DOD, and it has been questioned whether the lesions produced by copper deficiency are the same as those most often seen in the field (Pagan, 2000). Copper deficiencies may either be primary in origin because of a lack of copper intake or induced (secondary) due to interactions with other substances in the ration. Zinc (Zn) and molybdenum (Mo) have often been implicated as minerals that can interfere with copper absorption in horses, but several studies have suggested that neither zinc nor molybdenum (Pagan, 2000) affects copper utilization when fed at levels found in practical diets. Pagan (1998b) found significant negative correlations between true copper digestibility and the concentration of both crude protein and calcium in 30 different diets. These interactions may be particularly relevant when horses are fed predominantly legume forage or given several calcium supplements.

Zinc is present as a component of many enzymes and the biochemical role of zinc relates largely to the functions of these enzymes. Pagan (1998) evaluated interactions between zinc digestibility and a number of nutrients in 30 different diets. The only nutrient that was significantly correlated to zinc digestibility was magnesium. None of the trace minerals, including iron, affected zinc digestibility. There are no studies examining the intake of zinc in the diets of mares and bone development in their offspring.

Manganese deficiency has not been seen in horses. From research in other animals, manganese is known to be involved in several metabolic processes including cartilage formation. Unfortunately, little research on this mineral has been conducted with horses.

Lewis (1995) and other authors stated that because milk is a poor source of trace minerals for the foal, there is no correlation between the amount of copper, iron, and zinc in the mare's diet and levels in the milk. In contrast, iodine and selenium concentrations in milk are correlated with consumption by the mare. However, the source of the trace minerals may have an impact.

A chelated mineral is a type of organic complex that has a specific chemical structure. Minerals are usually chelated to an amino acid to improve uptake by the digestive system. Trace minerals in organic sources are believed to be more available (more easily absorbed from the digestive tract) than inorganic sources. Unfortunately, few experiments have compared organic and inorganic sources of minerals in horse feeds.

A study conducted at the University of Florida (Ott et al., 1994) examined the influence of inorganic or organic trace mineral supplementation of late pregnant mares on the trace mineral status and growth of their foals. Mares were fed from 56 days prior to foaling to weaning at 112 days of age. Trace mineral supplementation of mares had little effect on their serum concentrations, reproductive performance, or weight gains. Supplementation had no impact on foal growth, development, or bone mineral deposition, but foals nursing mares receiving organic copper, zinc, and iron had significantly higher plasma copper levels at 112 days of age and higher zinc levels at 14 days after foaling. It could not be determined if this difference resulted from higher mineral levels in milk or from the foals eating the mare's feed. The beneficial effect on trace mineral levels in the plasma of foals was only noted with chelated minerals; however, the diets were supplemented with relatively low amounts of copper, zinc, manganese, and iron.

Other studies have not shown superior absorption of organic minerals. Organic mineral sources are considerably more expensive than inorganic sources. More research will be necessary to determine whether including organic mineral sources in horse feeds provides enough benefit to justify the additional cost and which classes of horse benefit most significantly from organic supplementation.

Iodine (I) is an essential nutrient for reproduction and normal physiological function in the horse. Thyroxine (T_4) contains iodine and this hormone, along with triiodothyronine (T_3), has powerful effects on the overall health of the horse. These hormones influence nearly every process in the body, from heat regulation and feed utilization to proper bone growth and maturation. Iodine deficiency may result in goiter as the thyroid becomes enlarged in an attempt to produce adequate levels of thyroxine. Goiter often occurs in the foal at birth. Foal goiter may result from a deficiency in iodine in the mare's ration during pregnancy, or it may be caused by a goitrogenic substance. Symptoms of iodine deficiency may be stillbirth or a very weak foal that cannot stand and nurse. The foal may also have a rough hair coat, contracted tendons, angular limb deformities, or other abnormal bone development. There can be dramatic seasonal variation in the iodine intake for grazing animals with low intakes recorded during spring when many mares are in the final stages of pregnancy (Caple, 1991).

While iodine deficiency is the primary cause of goiter in foals, excessive levels of iodine may also cause this condition. The maximal tolerable dietary concentration of iodine has been estimated to be 5 mg/kg (ppm) of dry matter (NRC, 1989), equivalent to 50 mg I/day for a horse consuming 10 kg of dry matter daily. The horses most sensitive to high iodine levels are foals from mares who are supplemented with high levels of iodine. Iodine is concentrated across the placenta and in milk so that the fetus and nursing foal receive much higher concentrations than are present in the mare's ration. Therefore, goiter may be present in newborn foals while sparing the mother. A dietary intake of 83 mg I/day is the lowest level reported to have caused goiter in a horse more mature than a suckling foal (Drew et al., 1975).

Baker and Lindsey (1968) reported that foals with goiter were born on three farms that were feeding mares high levels of iodine. The incidence of goiter was proportional to the level of iodine fed and was 3% on one farm feeding 48-55 mg I/day, 10% on a farm feeding 36-69 mg I/day, and 50% on another farm feeding 288-432 mg I/day. A nearby farm, which did not have any affected foals, fed iodine at a rate of 6.3-7 mg I/day. Drew et al. (1975) reported that on one stud farm in England four foals were born with greatly enlarged thyroids and leg weaknesses. One mare also had an enlarged thyroid. Feed analysis showed that the mares had received 83 mg I/day from a proprietary feed during pregnancy.

The year before the mares received a supplement which supplied about 12 mg I/day, and there was no problem with goiter on the farm.

It appears from these reports that around 50 mg of dietary iodine is required in the daily rations of mares to produce any incidence of goiters in their foals. Toxic dietary iodine concentrations may result from adding excessive supplemental iodine, such as from ethylenediamindihydroiodide (EDDI), to concentrates or from using feedstuffs high in iodine. A common feedstuff that may contain excess iodine is kelp (*Laminariales*), a specific family of seaweeds that may contain as much as 1,850 ppm iodine (NRC, 1989). Unfortunately, people have a tendency to classify all seaweeds as kelp. There are numerous other specific seaweeds that contain considerably less iodine than kelp (Pagan, 2000). The iodine content of seaweed meal and kelp products should be examined prior to feeding to pregnant mares and intake must be carefully controlled.

Selenium (Se) plays an important role in the maintenance of membrane integrity, growth, reproduction, and immune response. A deficiency of selenium in foals may produce white muscle disease, a myopathy which results in weakness, impaired locomotion, difficulty in suckling and swallowing, respiratory distress, and impaired cardiac function (Dill and Rebhun, 1985). Although nutritionists tend to think of selenium as an antioxidant with major roles in immune function and muscle, Hintz (1999) proposed a link between selenium and skeletal disorders. "Kaschin-Beck disease (a chondrodystrophy in men in China) is associated with selenium deficiency. It has also been suggested that the mold Fusarium might also be involved. A toxin extracted from *Fusarium tricenatum* can cause a decrease in collagen microfibroids in chicken embryo chondrocytes. The addition of selenium prevented the decrease (Reilly, 1996). It has been suggested that selenium might help prevent Kaschin-Beck disease by its effect on *Fusarium* in the food (Reilly, 1996). Tibial chondroplasia in growing chicks can be caused by *Fusarium*. Tibial chondroplasia in chicks is similar to osteochondrosis in foals. Would there be a benefit from increasing selenium intake if foals or mares were consuming moldy feed?"

VITAMINS

Vitamin A is best known for its role in vision but also has functions in reproduction, differentiation of epithelial cells, embryogenesis, and growth. Vitamin A is found in abundant quantities in fresh green forages in the form of carotenes, which are converted to vitamin A by enzymes in the intestinal mucosa. Once forage is cut, there is rapid oxidation of carotenes (up to 85% within the first 24 hours and then about 7% per month during storage), which results in hay being practically devoid of carotenes after extended storage (McDowell, 1989). Horses on hay-only diets had depletion of vitamin A liver stores over a relatively short period of time (Fonnesbeck and Symons, 1967; Greiwe-Crandell et al., 1995).

Vitamin A has a distinct role in growth of the horse. Both deficiency and toxicity of vitamin A adversely affect growth, body weight, and rate of gain in young growing ponies (Donoghue et al., 1981). This retardation of growth may have reflected impaired cell proliferation and differentiation. Bone remodeling is modulated by vitamin A in the growing animal. Vitamin A's role in bone remodeling is in the proper functioning of osteoclasts, the bone cells responsible for resorption of bone. Without sufficient vitamin A, excessive deposition of periosteal bone occurs. Vitamin A deficiency causes bones to be shorter and thicker than normal (Fell and Mellanby, 1950). This is in part caused by the dysfunction of osteoclasts but also by a reduction in the degradation of glycosaminoglycans and the synthesis of proteoglycans also caused by deficiency (Dingle et al., 1972).

It is possible that some of the systemic effects of vitamin A on growth, as well as the poor growth usually associated with vitamin A deficiency, are related to its effects on growth hormone secretion. Vitamin A takes different functional forms once it is working in the body, one of which is retinoic acid, which has been found to affect growth hormone regulation (Sporn et al.,1994). Retinoic acid can synergize with either thyroid hormone or glucocorticoids to enhance the transcriptional activity of the growth hormone gene and subsequently of growth hormone secretion from cells (Bedo et al., 1989). Retinoic acid is also essential for embroyonic development during pregnancy.

For horses grazing sufficient quantities of green pastures, their vitamin A requirement can be met entirely by the carotenes in the forage (Greiwe-Crandell et al., 1997a). In northern states and countries, vitamin A supplementation is particularly important because of the short growing season of grasses. Depletion of vitamin A reserves in pregnant mares was found within two months of a diet of hay and vitamin A-free concentrate. Subsequent supplementation of vitamin A palmitate at two times the NRC recommended level was not adequate to completely replete stores of vitamin A in mares with no access to pasture (Greiwe-Crandell et al., 1997a). Mares with access to green pastures had adequate liver stores of vitamin A regardless of vitamin A supplementation. Additional vitamin A palmitate did not induce any excesses of vitamin A in liver or serum (Greiwe-Crandell et al., 1997a). Further investigation on ß-carotene found carotenes in grass readily available as a source of vitamin A, but synthetic ß-carotene was not readily absorbed. Use of synthetic ß-carotene as a sole source of vitamin A could not meet vitamin A requirements of horses and is not recommended (Greiwe-Crandell et al., 1997b). Vitamin A has been found to be of critical importance to the late pregnant mare. Studies by Greiwe-Crandell (unpublished) showed that if mares are maintained on hay alone with no green pasture and no vitamin A supplementation, the subsequent growth rates of their foals are significantly reduced up until 12 months of age compared to foals of mares with adequate vitamin A intake.

Vitamin D is known as the sunshine vitamin since it is made on the skin from 7-dehydrocholesterol by a reaction catalyzed by ultraviolet (UV) light. The function of vitamin D is maintenance of calcium homeostasis in the blood (McDowell, 1989). Circulating calcium is used for normal mineralization of bone as well as for a host of other body functions. Parathyroid hormone (PTH) and calcitonin function with vitamin D to control blood calcium and phosphorus concentrations. When blood calcium is low, the parathyroid is stimulated to release PTH. PTH travels to the kidney and stimulates conversion of 25-OH vitamin D to form the active vitamin (1,25 OH vitamin D). Active vitamin D then stimulates intestinal calcium uptake, stimulates bone mineral release, and stimulates resorption of calcium by the kidney, all in an effort to restore blood calcium levels (Linder, 1991). Calcitonin regulates high serum calcium by depressing gut absorption, halting bone demineralization, and slowing resorption in the kidney.

Since vitamin D is readily synthesized and absorbed from the skin, is it necessary to supplement vitamin D in the diet? In modern horse production systems, show horses are often kept out of the sunlight to prevent dulling of the hair coat. For horses not exposed to sunlight or artificial light with an emission spectrum of 280-315 nm, the NRC (1989) has established a requirement for dietary vitamin D. Pregnant and lactating mares require 800 IU of vitamin D per kg of diet dry matter according to the NRC (1989). The actual vitamin D intake would likely be less than calculated since vitamin D is lost at a rate of 7.5% per month with hay storage (Lewis, 1995).

Vitamin D should not be given in an effort to treat developmental orthopedic disease (DOD) by increasing calcium and phosphorus absorption and bone mineralization. DOD has not been shown to be caused by vitamin D deficiency and supplementation with vitamin D will not make up for diets that are not properly fortified with calcium and phosphorus. Oversupplementation of vitamin D to horses is toxic and results in extensive mineralization of cardiovascular and other soft tissues (Harrington and Page, 1983). Care should be taken to remain well below the maximum tolerance level (2200 IU/kg diet) established by the NRC in 1989.

Vitamin K was the last fat-soluble vitamin to be discovered (McDowell, 1989). For many years, vitamin K has been known for its blood-clotting function. Recently, the carboxyglutamyl residues have been found in other proteins associated with a variety of tissues. Most notable is osteocalcin, a protein involved in bone metabolism. Osteocalcin is responsible for binding to hydroxyapatite and facilitating bone mineralization. Undercarboxylated osteocalcin does not bind hydroxyapatite with the same affinity as carboxylated osteocalcin (Knapen et al., 1989). If vitamin K is in short supply, one would expect to find irregularities in blood clotting along with undercarboxylated osteocalcin. However, it is suspected that osteocalcin is more sensitive to low vitamin K activity than are the blood-clotting proteins (Duren and Crandell, 1989). Therefore, it seems possible that bone tissue may be vitamin K deficient, while liver, and thus the blood-clotting mechanism, is vitamin K adequate. If vitamin K has a positive effect on net bone formation, it might be expected that vitamin K antagonists (coumarin) have an opposite effect. Pastoreau et al. (1993) reported that lambs treated with vitamin K antagonists (warfarin) had strongly decreased bone formation indicated by a 30% lower bone mass in three months compared to controls. A deficiency in vitamin K would be expected also to have negative consequences for bone health.

The NRC (1989) has not established requirements for vitamin K fortification of equine diets. Natural sources of vitamin K are phylloquinone, found in green leafy plants, and menaquinone, which is produced by bacteria in the digestive system. Both phylloquinone and menaquinone are converted to the active vitamin (hydroquinone) in the liver (Lewis, 1995). The NRC (1989) states that if the intake or intestinal synthesis of vitamin K is inadequate, horses will have an increased susceptibility to hemorrhage. With new functions of vitamin K being explored, the previous statement may no longer be true. With current research interest, look for nutrient requirements for vitamin K in horse diets in the near future. At the present time, the NRC (1989) indicates that oral intake of phylloquinone and menadione appears to be essentially innocuous in horses.

Feeding Practices

BODY CONDITION

One of the most important aspects of broodmare nutrition is keeping the mare out of negative energy balance and preventing significant loss of body condition. Mares have an optimum body condition and are probably most efficient when kept at or near that condition. Establishment of the ideal condition comes from a combination of visually appraising the mare's condition and recording her body weight over time. Mares can differ in shape and weight and be remarkably similar in condition. Mares in optimum condition should have adequate fat over the ribs, behind the shoulder, and over the topline. Ribs should be covered and not easily seen but should be readily palpated. Once the optimum condition is determined, it should be maintained as a minimal acceptable condition. There are times when maintaining this condition requires a lot of feed and other times when little feed is required.

A number of studies have demonstrated the link between body fat content, body condition scores, and fertility. Although reproductive efficiency will be enhanced if mares are kept in a body condition score range from 3 to 4.5, it has been suggested that obesity may lead to a reduced milk output (Kubiak et al., 1991). Mares should be managed to keep them in body condition scores of less than 4.5 to maintain milk production and prevent metabolic disorders such as laminitis. A body condition scoring system of 0 to 5 has been developed for use in Australia (Figure 1) (Huntington, 1991). The Texan 1-9 system is used in other countries.

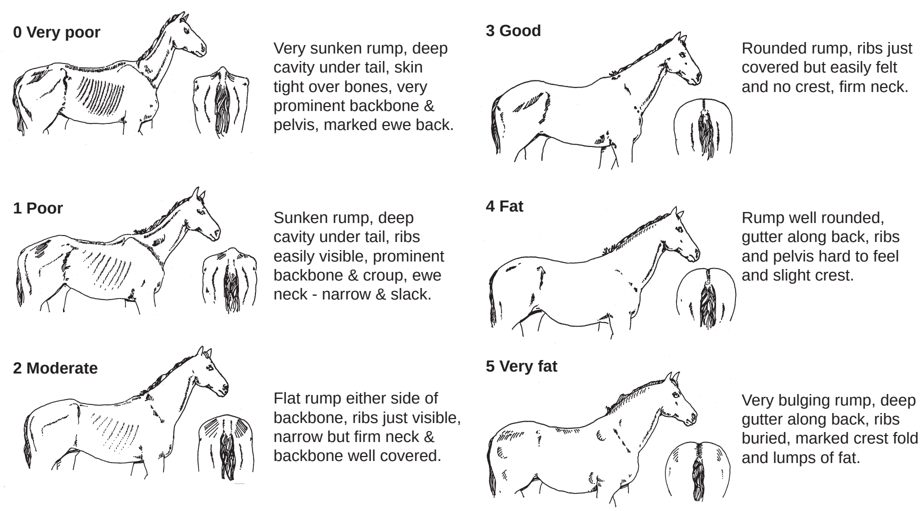

Figure 1. Body condition scoring system.

The effect of loss of body condition on reproductive performance is well documented. For this reason it is undesirable to send mares to stud too fat. The combination of a change of environment, pecking order, and feeding program may cause a mare to lose weight and reproductive efficiency. The only safe time to adjust a mare's body weight by diet is between weaning and the last 3 months of pregnancy.

There is anecdotal evidence that fat late pregnant mares have a greater incidence of delivering foals with angular limb deformities (ALD). In an Australian case report, a very high incidence of ALD was related to excessive energy intake in a group of thin mares, which led them to be obese at the time of foaling (Mason, 1981). It has been speculated that this relates to excessive internal fat in the mare leading to compression of movement of the foal in utero, but this seems an unlikely reason. Hormonal changes related to obesity such as insulin resistance may be more relevant explanations. Exercise is important for all horses and obese mares appear to move around paddocks less than mares that are not carrying an extra 100 kg of fat. This tends to perpetuate the obesity as energy consumption by exercise is reduced. Breeders should provide late pregnant mares with adequate opportunities for free-choice exercise. Hills are desirable as they increase the intensity of exercise but are not always available on horse farms. In some situations fat pregnant or barren mares would benefit from forced exercise on automatic walkers. While exercise is desirable, a study by Sparks (1999) showed that restriction of movement during pregnancy did not change the birth weights of foals when compared to mares allowed free exercise.

How much weight should a mare gain in pregnancy? Powell et al. (1989) showed that Quarter Horse mares gained 90 kg from day 65 to day 305 of pregnancy. Mares gained fat to day 205, were static during day 205 to 275, and lost weight in the last month of the study. In late pregnancy, the uterus and the growing foal consume 70% of the mare's blood glucose utilization (Rossdale and Ousey, 2002), and this is why some mares will lose weight in the last month before foaling. Very thin mares have been noted to reduce milk production and foal growth rate (Pagan et al., 1984; Gill et al., 1985; Doreau and Boulet, 1987), so keeping mares in good condition is desirable.

Although a few studs weigh their pregnant mares, it would appear to be desirable for mares to gain weight in late pregnancy. Studies conducted at Lindsay Park Stud (Baker, personal communication) have shown that early-foaling mares gained an average of 40 kg in the last 2 months while later foaling mares gained an average of 80 kg. The lower weight gain in the early-foaling mares was associated with changes in pasture quantity and quality and weather conditions during late winter compared with spring. It was also associated with lower birth weights, faster growth, and a higher incidence of valgus deformities of the knee. When management practices were changed to increase weight gain, this incidence of ALD in the foals born in August and early September was reduced. This change in management practices involved feeding greater amounts of a balanced concentrate feed so the mare would have received more energy, protein, and minerals. In contrast to these findings, Liu et al. (1984) have reviewed work from the United States and concluded that mares in good condition do not need to gain significant amounts of weight during late pregnancy in order to produce healthy foals.

FORAGES - PASTURE, HAY, AND CHAFF

Although the horse has evolved as a pasture-reared animal, the growth rate and reproductive efficiency of horses demanded by breeders means that many horses cannot be reared on pasture alone. However, it is desirable that the contribution to the diet of growing horses and mares made by pasture, chaff, and hay is maximized as horses are healthiest when fed a simple forage-based diet. Supplementation with concentrates or supplements is necessary to correct various nutrient deficiencies in forage.

To calculate accurately the contribution that forage makes to the horse's overall feeding program, forage intake as well as composition must be known. Weighing a dipper or using average figures can calculate chaff intake. Hay intake can be determined by simply recording the total weight of hay offered minus any hay wasted or refused. This does not take into account the differences in composition between hay that is eaten and hay that is wasted, but is accurate enough to do a good evaluation in the field.

The 1989 NRC gives estimates of forage and concentrate intakes based on the body weight of the animal and as a percentage of the total diet (Table 3). These figures can be used to establish reasonable concentrate and forage intakes for different classes of horses. Pasture intake is more difficult to estimate. Pasture intake will vary depending on the season, species, quality of pasture grazed, and the total amount of time that horses are allowed to graze. Another factor that has not been thoroughly studied is the effect that supplemental grain feeding has on pasture intake. Is pasture intake limited physically by the amount of time that a horse has to graze, or does the animal's total energy requirement dictate intake?

Table 3. Expected feed consumption by horses.

	% of body weight		*% of diet*	
	Forage	*Concentrate*	*Forage*	*Concentrate*
Horse				
Maintenance/early pregnancy	1.5-2.0	0-0.5	100	0
Late pregnancy	1.0-1.5	0.5-1.0	70	30
Early lactation	1.0-2.0	1.0-2.0	50	50
Late lactation	1.0-2.0	0.5-1.5	65	35
Young horses				
Weanling	0.5-1.0	1.5-3.0	30	70
Yearling	1.0-1.5	1.0-2.0	40	60

Several studies have evaluated pasture intake (Table 4). Moffitt et al. (1987) estimated grazing forage dry matter intakes for ten 2-year-old horses during December, May, and August to be 9.6 kg, but younger horses have been shown to consume less pasture than mature mares. This may be one reason why maiden mares often struggle to maintain condition.

Table 4. Estimates of pasture dry matter intake by horses.

Class of horse	*Pasture*	*Intake/hr (lb)*	*Duration (hrs)*
Mature horse	Fescue	3.30	3
Mature horse	Alfalfa	3.63	3
2-year-old	Fescue	0.91	24
2-year-old	Orchard grass	0.85	24

Actual pasture intakes may be 4 to 7 times the dry matter intake as some green pastures can be only 15-25% dry matter.

In Australia, Martin et al. (1989) studied pasture intake of mares and found that late pregnant mares consumed pasture at the rate of 1.6% body weight (DM) while lactating mares ate 2.3% body weight (DM). Provision of 2 kg/d of a concentrate pellet resulted in reduced pasture intake. There is no doubt lactating mares can eat large amounts of pasture as mares of certain breeds can produce enough milk for rapid growth in their foals while on pasture alone. These mares are producing 3-4% of their body weight in milk and are probably consuming a similar quantity of pasture dry matter. Obviously the quality and quantity of pasture available have a significant bearing on the consumption level and the ability of the mare to produce enough milk on pasture alone.

Unlike horse breeders in New Zealand and the United States, many Australian breeders pay little attention to pasture analysis. The relevance of pasture analysis is to pinpoint nutrient deficiencies, which need to be determined so appropriate levels of mineral supplementation can be offered. Most pastures have higher calcium than phosphorus levels, a situation that matches the requirements of the horse. Of particular relevance to skeletal development is the low calcium and high phosphorus levels combined with very low availability of calcium in high-oxalate pastures such as kikuyu. Reversals of the normal calcium to phosphorus ratio can occur on a temporary basis in certain pasture types in late winter and early spring. The level of copper and zinc supplementation needed in late pregnancy can be determined best by pasture analysis at the relevant time of year.

THE BARREN AND EARLY PREGNANT NON-LACTATING MARE

Both of these classes of mares have the same nutrient requirements as the mature horse at maintenance (Table 1). The most common mistake made in feeding broodmares is overfeeding the early pregnant mare. About 80% of the growth of the foal in the pregnant mare occurs in the last 4 months of pregnancy. The goal for the early pregnant mares should be to maintain body condition. If good-quality pasture or hay is available, the normal mare should need no supplementary feed other than a trace-mineralized supplement and a salt block. Warmblood mares and other easy keepers do not need grain in most situations, as their efficient metabolism allows them to consume lower amounts of energy for maintenance (Table 2). Obviously, if pasture is limited or if hay is in short supply, pellets, grain, or sweet feed may be used to effectively meet the mare's energy needs. Another factor is weather; if winter rain and cold are factors, supplementary energy may be required. Intakes vary but should not exceed 3 kg concentrates for the average mare. Higher intakes may be needed if a gain in condition is desired and mares should be grouped accordingly. The mare should not put on too much weight in early pregnancy.

Many dry and early pregnant mares are fed a diet that does not contain any supplementary minerals or vitamins. While this diet will result in theoretical nutrient deficiencies, it does appear that mares, if they have access to some green pasture, can reproduce efficiently and have foals that develop normally under these conditions.

However, under dry conditions (summer or winter), the intake of vitamin A from pasture declines dramatically and added vitamin A from a feed or supplement may be needed. At this time it is likely that mares will be "hard fed" (fed a concentrate). Most, but not all, prepared feeds and supplements contain enough added vitamin A, and supplementary hay, provided it is fresh and has retained its vitamin A content, will also help add vitamin A to the diet.

THE MARE IN LATE PREGNANCY

As the mare enters the ninth month of pregnancy, her nutrient needs increase significantly because of the demands of rapidly increasing fetal growth. She needs more energy, protein, minerals, and vitamins than the early pregnant mare (Table 1). If the diet does not supply adequate nutrients for fetal growth then the mare can utilize her own reserves to an extent, but it would appear that these diets can also cause an increase in the incidence of developmental orthopedic disease. Some of these disorders may not present until after weaning, but the feeding of the mare in late pregnancy can have a major impact on the wastage rate and the development in young horses. One of the critical areas relates to trace mineral nutrition, as milk is a very poor source of trace minerals and the foal needs to store trace minerals in its liver to cope with the deprivation that occurs while it is on a milk-based diet.

Although the late pregnant mare is able to meet her energy needs from forage alone if she is grazing suitable pasture and hay, she is unable to meet her other nutrient requirements in this manner. If an abundant supply of good-quality pasture is available, one may feed a mare 1 kg of a 20-25% protein concentrate pellet that contains added minerals to meet the mare's nutrient needs. Clearly, this would apply more to the early foaling mare and breeds that hold condition well, as pasture availability may become marginal during the late autumn and throughout the winter.

A more common manner of meeting the late pregnant mare's nutrient needs is to provide her with 3-5 kg/d of a 13-15% protein feed such as that described in Table 5, so the mare is required to meet a smaller percentage of her nutrient needs with forage. If abundant grass, hay, or both are available, the mare fed in this manner will probably gain weight. The protein content of the pasture will determine the specific protein level required in the concentrate. A critical aspect of this phase of the nutritional management of the mare is to maintain body condition and perhaps even slightly increase fat stores.

Protein quality becomes an important issue in late pregnancy as birth weight can have a significant impact on the eventual body size or growth rate of the foal. The amino acid that is most likely to be deficient in the mare's diet is lysine. Lysine content in the protein of cereal grains and many other protein sources such as cottonseed meal and linseed meal is low. Lysine is plentiful in the protein from milk products and soybean meal. Therefore, it is important that the mare receives feeds that include plenty of lysine for proper fetal growth. In the last four months of pregnancy, the equine fetus will deposit about 8 kg of protein as it grows to an average birth weight of 55 kg. During the last month of pregnancy the fetus will deposit over 3 kg of protein into its body. If people are mixing their own feeds, then they should use soybean meal as the protein supplement of choice in late pregnancy or use a supplement pellet or a concentrate that has high lysine content (Table 5). The hay of choice for the late pregnant mare is obviously a legume, lucerne (alfalfa) or clover hay that has a high protein and lysine content.

The first foal of a mare is often smaller than subsequent foals. French research has identified that first foaling mares ate 10% less feed than multiparous mares, and the resulting foals were 10% lighter (Doreau et al., 1991). This difference in nutrient intake can be addressed by paying special attention to feeding of the late pregnant mare that is foaling for the first time. Older mares also benefit from the same individual attention.

Table 5. Key nutrient specifications of feeds for mares.

Nutrient *feed intake*	*Balancer* *1 kg*	*Mare feed* *3 kg-7 kg*
Protein (%)	20-25	13-15
Lysine (%)	1.5	0.7-0.75
DE (MJ/kg)	11	12.5
Calcium (%)	3.0	0.8
Phosphorus (%)	2.0	0.6
Magnesium (%)	1.0	0.25
Zinc (mg/kg)	400	120
Copper (mg/kg)	150	45

Selenium and iodine deficiencies in pasture can be regional in origin and can result in white muscle disease and hypothyroidism respectively in young foals. Both of these disorders are uncommon but in areas where selenium and iodine deficiency occurs, horse owners need to pay particular attention to the selenium and iodine content of a supplement or a feed.

THE LACTATING MARE

With the exception of the racehorse in heavy training, the lactating mare has the highest nutrient requirements of any class of horse. Although the mare has never been selected on the basis of her ability to produce milk, she actually does a very good job of it. Mares are thought to produce 3-4% and 2% of their body weight per day in early and late lactation, respectively. This milk production represents a significant daily secretion of nutrients by the mare. The amount of secreted energy, protein, vitamins, and minerals leads to an increased dietary requirement for these nutrients. In most parts of the world, it is doubtful that the Thoroughbred or Standardbred mare can do an acceptable job of raising a foal, conceiving, and maintaining a new pregnancy on pasture alone, so supplementary feeding will be needed. However, in countries like New Zealand, temperate climates and magnificent pastures mean that many mares do not require feeding to supply energy and protein needs for lactation. Other breeds such as warmbloods, Quarter Horses, and ponies do not need feeding unless pastures are very poor.

Unlike the late pregnant mare, energy intake is critical to the lactating mare. Therefore, a more appropriate feeding regime includes the use of a high-quality, energy-dense feed, such as the 13-15% protein feed previously discussed (Table 5). Assuming a minimal forage intake of 1.5% of body weight per day, practical ranges in feed intake are from 3.5-7 kg.

The extreme range seen in feed intakes of lactating mares points to the variability in the proportion of the mare's nutrient needs that is met by forage. As with other classes of mares, one should carefully monitor the condition of individuals. If mares are getting too thin, increase their feed. If they are getting fat, decrease it. Remember that many feeds designed for broodmares are formulated with Thoroughbred mares in mind. Feeding rates for other breeds (especially those breeds renowned for being able to survive on next to nothing) can be significantly lower than levels suggested for Thoroughbreds. In fact, some mares can survive on only pasture and a vitamin and mineral supplement, even when lactating, without any detriment to the foal or loss of condition.

Once again, lucerne hay or chaff or clover hay are the forages of choice for the lactating mare. Legume hay has a higher protein and energy content than grass hay. If grass hay or chaff is fed in large quantities, allowances need to be made in the formulation of a compatible concentrate. If the breeder is mixing his own feed, he needs to add some supplementary protein to the grains used. Oats will generally be the staple grain and supplementary protein can generally come from soybean meal, full-fat soybean meal, or lupins. Commercial balancers and concentrate that supply protein are also used. There is a practical limit to the intake of soybean meal per day and this is about 500 g. There are benefits to using pelleted concentrates or those that don't leave any fines in the feed bins. If mares are receiving more than 3 kg of concentrate feed per day, they should be fed twice a day. This also provides another opportunity for early detection of illness or disease in foals. Pellets are an economical alternative for feeding lactating mares, but only use pellets that are designed for mares.

One of the determining factors in the decision to creep feed foals revolves around the nutrient content of the mare's feed. If a suitable fortified feed is used, it may be preferable to provide enough feed so that the foal can eat with the mare. On the other hand, if pasture grasses are plentiful or if the supplement for the mare is just oats or unfortified grains, then a creep feed is more desirable. Foals and weanlings need more concentrated feeds than mares because they are growing rapidly and have restricted appetites.

Although the economics of feeding fat to lactating mares does not justify its widespread use, adding fat to the diet from oil, sunflower seeds, or rice bran can assist in maintaining a positive energy balance in the lactating mare. The fat content of prepared feeds is on the label or oil can be added to the feed. Remember that 2 cups of oil supplies about the same amount of energy as 1.2 kg of oats and could be a valuable aid in feeding the mare that is producing a large quantity of milk and losing weight.

Lactating mares require large amounts of quality protein. The lactating mare needs twice as much protein as the dry mare because a mare's milk is high in protein and contains 20-25% protein on a dry basis. Milk protein is high in lysine, and the mare requires high-quality protein in her diet to produce it. In fact, the quickest way to decrease milk production in a mare is to restrict her protein intake but this can cause a decrease in foal growth. Sometimes this strategy is useful with mares that milk too well and foals that are growing too fast; however, dietary restriction needs to be managed carefully in the mare that is being bred again that season. Mares that are in a negative energy balance will be less reproductively efficient, and while an improvement in the growth of the current foal may occur, conception may be hampered. It would be nice to find a method to reduce milk production without impacting reproduction.

Trace mineral fortification is not as important for lactating mares as for late pregnant mares because milk contains low levels of these nutrients. Research has shown that adding more to the lactating mare's diet does not increase the trace mineral content of the milk. Calcium and phosphorus are the minerals of prime concern at this stage. If the foal is sharing the mare's feed bin, however, appropriate trace mineral fortification would be valuable.

In summary, the critical aspect of feeding the broodmare is maintaining the mare in good condition by meeting her energy needs while ensuring that her protein, vitamin, and mineral intakes are appropriate for the stage in the reproductive cycle.

Most studs pay much more attention to feeding the young growing horse than the broodmare, yet an increased focus on the broodmare could increase fertility and produce better young horses.

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