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MACROMINERALS - SODIUM, POTASSIUM AND CHLORIDE

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The importance of minerals in the diet of horses is well recognized by horse owners and equine nutritionists alike. The type and quantity of minerals required are very diverse and essential minerals include the major or macrominerals and the trace or microminerals. This discussion will be restricted to three macrominerals, sodium, potassium, and chloride (Na+, K+, Cl-), that are essential to the physiological well-being of the horse. Whereas certain assumptions are often made about the requirements for these three minerals, the demands for these minerals can vary substantially depending on age and activity. The following paper will elaborate on some of the basic dietary guidelines for sodium, potassium, and chloride and, by describing the role and use of these macrominerals in the body, provide a broader perspective as to how these basic requirements for the horse may be altered in different circumstances.

Sodium, Potassium and Chloride in the Body

All essential minerals can be detected in the tissue and fluids of healthy animals and sometimes reflect whether the mineral status of the animal is adequate or deficient. Distribution of minerals in tissues is not uniform; some tissues contain much higher concentrations of specific elements that are essential to that tissue's function. Perhaps the best known example is the structural support provided by concentration of calcium and phosphorus in bone. Equally important, although less obvious, are the complex biochemical, physiological and neurological functions of sodium, potassium and chloride. These elements are often essential for movement of specific ions across the cell membrane, for stabilizing enzymes in their most active conformation, and for maintenance of ionic and osmotic balance of intra- and extracellular fluids.

Sodium and chloride are the major ions found in extracellular fluids. Plasma sodium concentration, normally maintained within narrow limits, is the primary determinant of alterations in plasma tonicity and is important in the maintenance of acid-base balance in body fluids. Generally, of the sodium present in the horse's body, approximately 45% is present in extracellular fluid, 10% in intracellular fluid, and the remainder is integral to bone structure and is not available, consequently, for exchange with fluid compartments.

Whereas sodium and chloride are found predominantly in extracellular fluids, 90% of the body's potassium is retained within cells and, in particular, in skeletal muscle (70-75%). The retention of potassium largely within cells and of sodium in extracellular fluids is accomplished primarily by the action of specific ATP-consuming pumps (Na+-K+-ATPase), located within the cell membrane, that pump potassium into cells in exchange for sodium ions. The high intracellular potassium concentration, established by the constant work of Na+-K+-ATPase, maintains the elevated resting membrane potential in excitable tissues such as nerves and muscle, and has a crucial role in the triggering of action potentials that initiate muscle contraction and nerve impulse transmission. During exercise, there is rapid outflow of potassium from skeletal muscle that results in a transient rise in the concentration of plasma potassium with the extent of this hyperkalemia reflecting the intensity of exercise. This rise in plasma potassium can augment blood flow to working muscle through dilation of local arterioles. Upon cessation of exercise, the high intracellular potassium concentration in muscle is reestablished by Na+-K+-ATPase pump activity.

Sodium, potassium, and chloride are absorbed from the gastrointestinal tract. Whereas sodium is actively moved across the intestinal wall by an energy-requiring process, chloride and potassium diffuse from ingesta within the gastrointestinal tract across the intestinal wall with the rate being determined by their relative concentration in ingesta vs. the mucosal cells of the intestinal wall. Thus, when absorption is passive as is the case for chloride and potassium, the concentration of these ions in the feed and the quantity of feed in the intestine can significantly affect the amount absorbed by the gut. Transepithelial sodium transport has been demonstrated to be greater in distal as compared to proximal colon whereas 52-74% of potassium has been reported to be absorbed prececally, with less absorption in the large intestine (Meyer, 1987; Clarke et al., 1992). A few other factors can affect absorption of minerals in the intestinal tract. In particular, the age of an animal (young animals are more efficient in absorbing essential elements than older animals) and the pH of the intestinal tract can affect the rate of absorption (Lewis, 1995).

Effects of Sodium or Potassium Deficiency

When an adequate supply is available, horses normally consume sodium, potassium, and chloride in excess of their dietary requirements. Deficiencies of these minerals can occur when the quantity or the quality of certain feedstuffs in the diet limits their availability and/or when there are greater dietary demands based on growth, lactation, or activity. Consequently, there is a greater risk of sodium deficiency occurring during lactation or when horses are in moderate to heavy work. Secretion of the hormone aldosterone will increase in response to a reduced sodium intake, resulting in greater absorption and retention of sodium, and thereby lowering its excretion in urine, milk and sweat. When sweat production is decreased in an attempt to retain sodium, there is a greater likelihood of hyperthermia during exercise, reducing the rate of work and, as a result, performance capacity. In addition, there is evidence that significant electrolyte losses and subsequent electrolyte imbalances contribute to the development of exertional rhabdomyolysis ("tying up") in some horses (Harris, 1988).

Table 1. Concentrations of macrominerals in feeds.

	Amount in various feeds (% commonly present in dry matter)		
	Alfalfa	Grasses	Grains
Sodium	0.03 - 0.25	0.01 - 0.25	0.01 - 0.1
Potassium	1.0 - 4.0	0.5 - 3.5	0.2 - 0.7

Data adapted from Lewis,1995.

Most practical diets contain a sufficient quantity of potassium as a result of its relatively high concentration in most forage (Table 1). As intake of potassium in excess of requirements is excreted in urine, excess potassium in the diet rarely poses any difficulties. In contrast, a potassium deficiency can cause significant problems. When compared to human sweat, equine sweat has a high potassium content. Therefore, limited forage intake, substantial sweat losses due to strenuous and repeated exercise and/or hot ambient conditions are all factors that could contribute to a potassium deficiency. Aldosterone secretion, stimulated by loss of sodium in sweat fluid, serves to enhance sodium retention, but this conservation of sodium is accomplished by increasing potassium excretion. Thus, endurance horses that sustain large sweat fluid losses and undergo a period of reduced or no feed intake are particularly susceptible to substantial potassium loss. Potassium losses can also be exacerbated by the use of diuretics, such as furosemide (Lasix), commonly administered to racehorses in an attempt to reduce exercise-induced pulmonary hemorrhage. Finally, increased fecal potassium loss occurs in horses with diarrheal diseases and is often aggravated by the decreased feed intake associated with illness.

Potassium deficiency is more likely to occur when horses are maintained on a high grain, low forage diet. For example, when horses were fed a diet consisting of 1/3 grass hay and 2/3 oats, a diet commonly fed to horses in training or racing, a net loss of potassium occurred (Young et al., 1989). As stated earlier, approximately 75% of the body's potassium is found in skeletal muscle and is essential to its function. Therefore, muscle weakness, fatigue, and exercise intolerance are likely when potassium deficiency occurs (Table 2). In addition, decreased feed and water intake occurs in horses with potassium deficiency, and will serve to further reduce potassium intake (NRC, 1989).

Table 2. Sodium and potassium deficiencies: Causes and effects.

	Common causes	Effects
Sodium deficiency	Insufficient salt available as supplement and/or in feed Profuse sweating	Reduced sweating and performance Decreased food and water intake Dehydration, weight loss, constipation Restlessness, licking, pica
Potassium deficiency	Profuse sweating can be accentuated by: - a high-grain (low K+) diet - diuretic - diarrhea	Impaired muscle function and early onset of fatigue Decreased food and water intake Weight loss

Data adapted from Lewis,1995.

Dietary Requirements for Sodium, Potassium and Chloride

Maintenance requirements (sedentary horses)

Maintenance requirements for sodium, potassium and chloride have been estimated to be 20-25, 30-48, and 75-80 mg/kg body weight (BW) per day, respectively. For a 450 to 500 kg sedentary horse, this would amount to approximately 10 to 15 g/day of sodium, 15 to 20 g/day of potassium and 35 to 40 g of chloride (Coenen, 1999; Meyer, 1987; Schryver et al., 1987; Groenendyk et al., 1988; Hintz and Schryver, 1976). Most forages are high in potassium (0.5-3.5% and 1-4% DM in grass and alfalfa hay, respectively) (Table 1). Therefore, when fed in adequate quantity (at least 1% BW or a minimum of 5 kg for a 500 kg horse), maintenance potassium requirements can be met. Less data is available regarding chloride intake and requirements for the horse. However, recent work by Coenen (1999) has provided some insight into chloride requirements (Table 3). This work also demonstrated that chloride intake can vary from approximately 5 mg/kg BW/day (when horses are fed washed hay) up to 286 mg/kg BW/day when fed a ration of grain and hay. Whereas sodium content of grass and alfalfa is often far below 0.5 g/kg dry matter (DM), chloride content of forage is usually higher (estimated to be 7 to 10 g/kg DM). As such, there is greater risk of a deficiency of sodium than of chloride or potassium based on dietary intake (Jansson, 1999). The apparent digestibility of sodium, potassium, and chloride is approximately 90, 80, and 90%, respectively, indicating the efficient utilization of these macrominerals by the horse. Quantities in excess of requirements are normally excreted in urine. Intake of sodium and chloride also increases calcium and phosphorus absorption and retention.

Provision of sodium chloride requirements for nonexercised horses is often met by access to a salt block (when coupled with sodium intake in feed) (Schryver et al., 1987; Jansson et al., 1996). However, salt consumption by individual horses can vary significantly. In a study by Schryver and coworkers

(1987), voluntary salt intake from a block by mature unexercised horses averaged 53 g/horse/day but varied from 9 to 143 g/day between horses and from 5 to 200 g/day by the same horse on different days. Horses also preferred a grain mix without added sodium chloride when compared to a grain mix with 2 to 4% added salt. Other researchers reported that in 4 of 6 horses studied, voluntary daily intake of salt was less than 20 mg/kg/day (Jansson and Dahlborn, 1999).

Voluntary salt consumption normally increases in hot and humid weather and may increase if horses are on pasture during periods of plant growth (Lewis, 1995). A small number of horses, when restricted to box stalls and allowed free access to salt, consume excess quantities of salt as a result of boredom.

Table 3. Maintenance dietary requirements for macrominerals.

	Sodium (mg/kg/day)	Potassium (mg/kg/day)	Chloride (mg/kg/day)
Maintenance (minimum requirement)	10 - 15	20 - 25	20
Maintenance (recommended)	20 - 25	30 - 38	75 - 80
Late pregnancy, lactation and growth	25 - 30	40 - 55	85 - 95

Data adapted from Coenen,1999; Lewis,1995; Meyer, 1987; Schryver et al., 1987; Groenendyk et al., 1988; Hintz and Schryver, 1976.

Growth and lactation

During the first two months of life, a growing foal's requirements for sodium, potassium, and chloride can be met by adequate intake of the mare's milk. Subsequently, the growing horse should be provided with unlimited access to water and a salt supplement. Often this is a trace-mineralized salt that also contains significant quantities of copper, zinc, and selenium. It should also be recognized that although foals may start to eat solid feed within the first one to two weeks of life, many do not drink any water, relying completely on the mare's milk as its only source of fluids (Crowell-Davis et al., 1985). Thus, the lactating mare can sustain substantial losses of both fluid and electrolytes. As a foal can consume upwards of 25% of its body weight in fluid each day, a foal weighing between 80 and 100 kg could rely on its dam for as much as 20 to 25 liters of milk each day. Assuming a sodium and potassium concentration in milk of ~ 0.17 and 0.51 g/liter, respectively, the demands of the foal could result in the requirement for an additional 3 to 4 g of sodium and 10 to 12 g of potassium for the lactating mare. For both the mare and the growing horse, sufficient quantities of potassium and chloride can normally be provided by a diet that includes an adequate quantity of grass or hay. However, given the paucity of sodium present in many feeds, salt should be made available at all times and can be added to the grain at a rate of 0.5 to 1% DM to ensure that horses receive sufficient sodium and chloride.

Horses in Work - Meeting the Needs of the Equine Athlete

The muscular activity associated with exercise results in substantial energy expenditure. However, the process of conversion of metabolic energy to mechanical work is only 20 to 25% efficient with the result that 75 to 80% of the chemical energy is converted to heat within skeletal muscle cells (Hodgson et al., 1994; Jones and Carlson, 1995). Like human athletes, the principal mechanism of heat loss in the horse during exercise is evaporation, primarily in the form of sweating. Sweating rates of 35 to 50 ml/m^2/min have been measured for horses exercising on a treadmill in a laboratory (Hodgson et al., 1993; McCutcheon et al., 1995a; McCutcheon and Geor, 1996). For a 500 kg horse with a total surface area of 4.5 to 5.0 m^2, such sweating rates correspond to sweat fluid losses of 10 to 15 liters/hour; this is similar to estimated hourly losses during prolonged exercise in field conditions (Carlson, 1983). Therefore, prolonged or strenuous exercise results in significant fluid losses and, in addition, extensive losses of ions.

The predominant ions in equine sweat fluid are sodium, potassium, and chloride. Although the ratio of these ions present in equine and human sweat are similar, the absolute quantities are 4 to 5-fold higher in horses (Figure 1) (Costill, 1977; McCutcheon et al., 1995b; McCutcheon and Geor, 1998). Therefore, the need to ensure adequate replacement of sodium, potassium, and chloride losses is an even more urgent consideration for the equine athlete when compared to their human counterparts.

Several factors affect the extent of sweat fluid and ion losses associated with exercise. Sweating rate, which can be used to estimate the rate of fluid and ion losses, is largely determined by the duration and intensity of exercise undertaken. In racehorses, fluid losses over the course of a full day may be as high as 15 liters, and endurance horses participating in 80-160 km events often have a fluid deficit of 20 to 40 liters despite access to water during the ride (Carlson, 1987). Horses completing 45 km of trotting on a treadmill in cool conditions in a simulated endurance event were reported to have lost approximately 27.5 liters of sweat fluid and estimated sweat ion losses of 241 g in less than 4 hours (Figure 2) (Kingston et al., 1999). Despite the relatively short period of endurance exercise in this study, these losses are in excess of estimates of voluntary intake of these macrominerals in an unsupplemented diet.

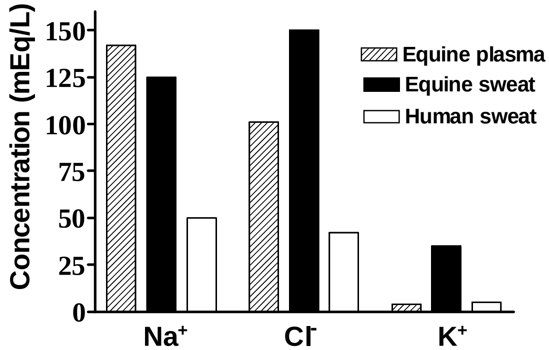

Figure 1. Comparison of the approximate concentration of sodium (Na+), chloride (Cl-), and potassium (K+) in equine plasma and in equine and human sweat, demonstrating the isotonic to hypertonic nature of sweat in horses compared to humans. (Data from McCutcheon et al., 1995b, McCutcheon et al., 1996; Costill,1977)

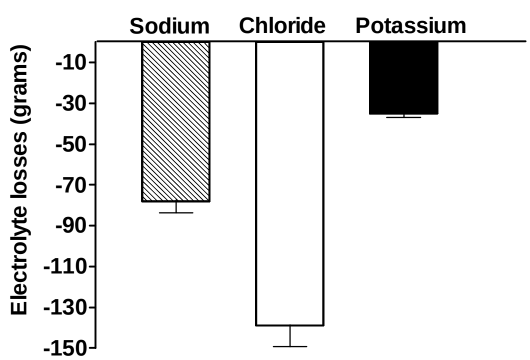

Figure 2. Electrolyte (sodium, chloride, potassium) losses in sweat in 6 Thoroughbred horses trotting for approximately 3 hours and 20 min (45 km) in moderate ambient conditions (20-24°C). (Data from Kingston et al., 1999)

In addition to exercise intensity and duration, other factors such as terrain, footing, the weight of the rider and tack, training status, and ambient temperature can contribute to the horse's work output and the need to increase dissipation of heat via sweating. Of these factors, the most important is the effect of the environment. Hot ambient conditions affect both the sweat ion composition and sweating rate (Table 4).

Table 4. Mean sweating rate of horses exercising on a treadmill at different exercise intensities and ambient conditions.

Mean sweating rate (ml/m²/min)		
Exercise intensity	Cool conditions	Hot conditions
Low (3.2 - 4.5 m/s)	21.1 ± 5.2	27.0 ± 6.2
High (9.0 m/s)	32.8 ± 5.1	52.3 ± 7.7

Data from McCutcheon and Geor,1996; McCutcheon and Geor, 1998.

Ion concentration of equine sweat is reported to be higher in hotter conditions; much of this increase is assumed to be a reflection of a higher rate of sweating under these more severe ambient conditions (McCutcheon et al., 1995b). Although sweat sodium concentration has been shown to decrease slightly in horses following training and in those acclimated to hot and humid conditions, this decline in the sweat sodium concentration was partially offset by higher sweating rates at a given body temperature (McCutcheon et al., 1999). The effects of higher ambient temperature on the extent of sweat fluid and ion losses was demonstrated in a group of six horses completing a treadmill speed and endurance test that simulated the speeds and distances required for each phase of an Olympic level three-day event in cool and hot ambient conditions. Total sweat fluid losses associated with the test in hot, dry conditions were almost double those measured in cool, dry conditions (Table 5) (McCutcheon and Geor, 1996).

Table 5. Calculated total sweat fluid and ion losses under different ambient conditions during training and a treadmill simulated speed and endurance exercise test

	Daily training		Speed and endurance test	
	Cool	Hot	Cool	Hot
Total fluid losses (liters)	4.6	11.3	11.7	19.2
Total ion (Na+, K+ and Cl-) losses (g)	43.5	115.2	112.3	200.6

Cool = 20-22°C, 45-55% relative humidity; Hot = 33-35°C, 45-55% relative humidity;
Daily training = 1 hr of submaximal exercise. Data from McCutcheon and Geor,1996.

The various studies described in this section demonstrate the increased demand for sodium, potassium and chloride for horses in regular work. This additional demand will be particularly high in horses in heavy work during the summer months. For horses in training and competition, it is important to meet these needs as ongoing heavy sweat losses without adequate replacement can result in electrolyte imbalances and/or depletion that contributes to poor exercise performance.

Supplementation

Most forages are deficient in sodium and marginal in chloride. In contrast, forage is high in potassium and when fed in adequate quantities normally meets daily potassium requirements. However, as a result of the many factors that can affect intake and the rate of loss of sodium, potassium, and chloride, it is recommended that these electrolytes be provided to all horses. As electrolytes consumed in excess of requirements are excreted in the urine, access should be provided on a continuous (daily) basis. These minerals can be provided to horses in their ration or as a separate supplement. Salt supplements can be offered loose, top-dressed on the feed, or as a block. It should be noted that most salt blocks and other supplements typically do not contain potassium. Therefore, if the roughage portion of diet is restricted (less than 1% BW on a dry matter basis) and/or high sweat losses occur as a result of hot summer weather and moderate to heavy work, then potassium supplementation may be necessary. Sometimes, electrolytes are added to drinking water. However, horses should be introduced to electrolyte solutions gradually and water intake monitored as electrolyte solutions can result in reduced water consumption in some horses. Similarly, addition of electrolytes to feed should be approached conservatively to avoid decreased feed intake.

In addition to daily supplementation, administration of hypertonic electrolyte pastes before or during competition is widely practiced by endurance riders. Electrolyte pastes may contain just NaCl, or a 50:50 mixture of NaCl and KCl mixed with water. Experimentally, these pastes have been administered as 80 g each of NaCl and KCl or 90 g of NaCl. To date, there is limited data on the efficacy of these pastes. While such salt pastes provide a portion of the electrolytes lost in subsequent work, the primary purpose of the mixture is to stimulate the thirst response and encourage voluntary water consumption in order to maintain extracellular fluid volume during the ride and aid post exercise recovery of fluid losses. The work of Lindinger and Ecker (1995) reported that endurance horses with less pronounced fluid and electrolyte alterations during a competitive ride were more successful than those with greater alterations although recovery did not differ between the two groups. In work by Nyman and colleagues (1996), it was reported that horses offered 0.9% saline or given a salt paste during a 62 km ride had higher fluid intake during the ride and faster recovery of their body weight when compared to horses offered water. However, based on increases in plasma sodium concentration during the ride, the authors cautioned against the use of the salt paste. It should be emphasized that in the horse, the gastrointestinal tract is a very important source of both fluid and electrolytes utilized both during and after prolonged exercise (Schott and Hinchcliff, 1998). The importance of dietary fiber in increasing this gastrointestinal fluid reservoir underscores the need to maintain good quality roughage in horses training and competing in prolonged events. Depletion of this reservoir appears to be one of the main reasons for persistent body weight losses during recovery from prolonged endurance exercise (Hyppa et al., 1996; Schott et al., 1997).

Recommendations for Different Classes of Horses

Maintenance (sedentary horses)

Sedentary horses require at least 10 mg/kg BW of sodium and chloride daily (approximately 10 g for a 500 kg horse). In supplementing the diet, NRC (1989) recommendations suggest that chloride requirements are adequately met when sodium supplementation is provided as sodium chloride. Provision of at least 0.1% sodium in diet dry matter (0.25% common salt, which is 39% sodium and 61% chloride) is the minimal suggested requirement. However, at least 0.3% (0.75% common salt) would more adequately ensure provision of daily requirements of these macrominerals under any management conditions. In order to meet potassium requirements, provide forage at a rate of at least 1% BW on a dry matter basis. For a 500 kg horse, approximately 5 to 6 kg of hay (DM) will provide 75 to 150 g of potassium.

Growth and lactation

Similar recommendations for salt (0.3% sodium, 0.75% common salt in diet dry matter) will meet the needs of growing horses, lactating mares and those in late gestation. Again, this recommendation would include intake of adequate quantities of forage to supply potassium requirements. Top-dressing feeds made available in a creep provides a mechanism to ensure salt supplementation in foals that may not take advantage of a salt block.

Horses in work

As indicated earlier, horses in work have additional demands for sodium, potassium and chloride to replace loss of these ions in sweat fluid. There is some increase in intake of these ions as additional feed is provided to offset the additional energy consumption associated with exercise. However, salt and potassium intake in additional feed will not be sufficient to compensate for increased losses. A commercial electrolyte supplement can be provided to meet these additional needs; composition of such supplements should be carefully evaluated to ensure the specific needs of a particular horse or group of horses are met. Alternatively, top-dressing feed with 150 g of a 50:50 mixture of NaCl and KCl should meet the needs of most horses in moderate work (sweat losses of approximately 10 liters/day). During and following periods of intense work, particularly in hot ambient conditions, supplementation in excess of 150 g may be required (Table 6). Dividing this supplement between two or three grain meals each day will enhance the palatability of the ration.

Table 6. Estimated sweat fluid losses and sodium, chloride and potassium requirements (in grams) for a 500 kg horse at different levels of work.

Workload:	Non-exercised	Low workload	Moderate workload	Strenuous and/or prolonged exercise program
Sweat losses (liters per day):	0-5	5	10	20
	Electrolyte requirements (grams) for a 500 kg horse			
Na+	10-15	25	45	90
Cl-	30-35	40	80	160
K+	15-20	30	45	80

Concluding Remarks

Sodium, potassium, and chloride are essential dietary requirements for all horses. Although present in grain and forage, the possible variation in quality, quantity and ratio of these two components of the diet leaves the potential for marginal or deficient intake of one or more of these minerals (particularly sodium). Furthermore, while access to salt should be provided at all times, dietary supplementation is a more accurate method of ensuring intake, as voluntary consumption of salt can vary significantly. Finally, loss of sodium, potassium, and chloride as a result of sweating will increase in hot weather and with the intensity and duration of exercise required by the horse. Therefore, supplementation of these minerals should be adjusted according to work required and ambient conditions.

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