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Mineral Imbalances and Animal Health: A Management Puzzle[1]

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Introduction

All animals, including humans, need nutrients, vitamins, minerals, and water to survive. Some of us, knowing that we do not get proper amounts of nutrients in our foods, take multivitamins to complete our diets and meet our vitamin and mineral needs. Livestock producers generally provide mineral supplements to meet the dietary requirements of their stock. We know that deficiencies in certain minerals can cause health problems. For example, low calcium intake causes thin and brittle bones. But, what if a person who consumed adequate amounts of calcium was also ingesting something else that "tied up" that calcium? The result would be brittle bones and would place an unaware person at risk. As livestock owners, would we know if there were mineral imbalances in what we feed our animals?

Key to Mineral Abbreviations

B	boron
Ca	calcium
Cl	chlorine
Co	cobalt
Cr	chromium
Cu	copper
Fe	iron
I	iodine
K	potassium
Li	lithium
Mg	magnesium
Mn	manganese
Mo	molybdenum
N	nitrogen
Na	sodium
Ni	nickel
P	phosphorus
S	sulfur
Se	selenium
Si	silicon
Zn	zinc

Plants and animals need proper amounts of minerals to achieve maximum health and production. Knowledge of mineral requirements of forage plants and grazing animals is essential to understand the complex interactions that one element may have on another. Deficiency or excess of dietary mineral elements may cause animal production and health concerns. The study of simple mineral deficiencies in animal diets is not new. However, the interactions among minerals and their subsequent imbalances are relatively new areas of study in animal nutrition. In addition, when minerals are out of

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balance they can directly or indirectly affect bioavailability of other minerals. This means that an animal may show signs of a mineral deficiency even though it is getting the "required amount" of that mineral.

Grazing animals require 8 macronutrients. This list includes the 6 needed by plants (N, K, Ca, Mg, P, and S) plus Na and Cl. Animals require some of the same micronutrients as plants (Cu, Fe, Mn, Mo, and Zn) plus Co, I, and Se. Animals may also require ultratrace quantities of Cr, Li, and Ni. Often grass and forb diets will contain nutrient levels considered adequate, but the bioavailability of some minerals may be reduced because of interactions like K x Mg, Mo x Cu x S, and S x Se. Mineral management for livestock production requires a general idea of mineral requirements and concentrations found in forage plants (Table 1).

Grasses may not provide sufficient macronutrients (N, Ca, Mg, P, and S), micronutrients (Cl, Cu, or Zn), or other elements (I, Na or Se) and, thus, fail to meet the animal's nutritional needs. Pastures of cool-season grasses are often fertilized with N and K. If N-fixing legumes are grown then P may be applied and N fertilization will be minimized or even omitted. Grazing animals are generally supplemented with salt (NaCl) and may receive additional amounts of I, Se, Zn, and Co trace mineral to supplement their forage diets. Ruminants may also receive supplementary Mg where there is risk of grass tetany.

Forages in some geographic areas may contain sufficient mineral nutrients to maintain herbage growth, but insufficient amounts of Cu, Mg, S, Se, or Zn to meet animal requirements. For example, tall fescue is well adapted to many areas of the U.S. Soils in these areas contain little plant-available Se and research shows that plants growing in these areas may not take up sufficient Se to meet animal requirements. Management programs that allow for direct or indirect supplementation of these nutrients to the animals should be considered.

Magnesium, Potassium, Calcium and Their Interactions

Grass tetany (hypomagnesemia), induced by a Mg deficiency, may be the most important health problem in ruminants caused by mineral imbalances. Although forage containing 0.2% Mg (2 g Mg/kg DM) is adequate to meet Mg requirements in most situations, cows and ewes near parturition and continuing into lactation may need extra Mg (10 to 30 g Mg/cow/day, 2 to 3 g Mg/ewe/day). Magnesium absorption by herbivores is negatively affected by K, and forms the basis for the K/(Mg+Ca) index in forages that indicate risk level. Calcium is included in the index because it counters some of the effects of K on Mg absorption. The risk of grass tetany increases exponentially when the herbage K/(Ca+Mg) index increases above 4.4 when expressed on a mass basis (g/g or percentage by weight). Other factors that reduce Mg availability to ruminants include high concentrations of N and low concentrations of soluble carbohydrate (e.g., sugars and starches).

Table 1. Nutrient element concentrations normally found in cool-season grasses and legumes and their requirement by sheep and cattle.

	Concentrations in Forages		Dietary Requirements	
Element	Grasses	Legumes	Sheep	Cattle
	---Macronutrients (g/kg)---			
Calcium, Ca	3 - 6	3 - 14	3 - 4	3 - 4
Chlorine, Cl	1 - 5	1 - 5	1	2
Magnesium, Mg	1 - 3	2 - 5	1	2
Nitrogen, N	10 - 40	10 - 50	10 - 15	10 - 15
Phosphorus, P	2 - 4	3 - 5	2	2
Potassium, K	10 - 30	20 - 40	3	8
Silicon, Si[1]	10 - 40	0.5 - 1.5	requirement not established	
Sodium, Na[1]	0.1 - 3.0	0.1 - 2	1	2
Sulfur, S	1 - 4	2 - 5	1 - 2	1 - 2
	---Micronutrients (mg/kg)---			
Boron, B	3 - 40	30 - 80	requirement not established	
Copper, Cu	3 - 15	3 - 30	5 - 6	7 - 10
Fluorine, F[1]	2 - 20	2 - 20	1 - 2	1 - 2
Iron, Fe	50 - 250	50 - 250	40	40
Manganese, Mn	20 - 200	20 - 200	25	25
Molybdenum, Mo	1 - 5	1 - 10	<0.1	<0.1
Zinc, Zn	10 - 50	15 - 70	25 - 40	25 - 40
	---Trace elements (micro-g/kg)---			
Cobalt, Co[1]	50 - 300	200 - 300	100	60
Chromium, Cr[1]	200 - 1000	200 - 1000	Trace	Trace
Iodine, I[1]	40 - 800	40 - 800	500	500
Nickel, Ni	200 - 1000	200 - 1000	60 - 70	60 - 70
Selenium, Se[1]	50 - 200	50 - 200	30 - 200	40 - 300

[1]Required by animals but not by grasses or legumes.

Dietary requirements are for growing sheep and lactating beef cattle. Requirements may be different for other animal classes.

Grass tetany mainly affects older lactating cows grazing fertilized cool-season grasses in the early spring, about 2-4 weeks after turnout. Sheep are also susceptible, especially lactating ewes with twins. The signs of grass tetany in cattle include reduced intake of feed, reduced milk production, and nervousness or muscle twitching around the face, head or shoulders. As tetany progresses, the cow will stagger and fall, throw her head back, salivate and grind her teeth, and may paddle her feet. Convulsions, coma, and death soon follow. Sheep show similar symptoms, except initially they may simply hang their heads, separate from the flock, and try not to move. Symptoms may be detectable for less than 4 hours.

Severity of economic livestock losses can be reduced by delaying early spring use of grass pastures, grazing with stocker or dry cows, and supplementing animals with soluble Mg. The Mg may be provided in drinking water (using water soluble magnesium sulfate or magnesium acetate), licks, salt, or perhaps as a dust on the forage. On acid soils, liming with Ca-Mg limestone (dolomite) rather than calcium limestone (calcite) would increase Mg availability to plants and likely to grazing animals.

Prudent use of N and K fertilizers can minimize risk of grass tetany. Split applications of K fertilizer, where used, will minimize the impact of high K levels on Mg availability to the plant and subsequent grazing animals. Aluminum in acid soil solutions may also reduce Ca and Mg uptake by cool-season grasses and increase susceptibility to grass tetany. Restoring available soil P to concentrations adequate for good plant growth can also elevate Mg and Ca concentrations in grass leaves.

Assessments of mineral concentration must also keep an eye on K levels in dry-mature or winter grass (standing or harvested), as they may be inadequate for cattle requirements. This may occur because of weathering and leaching of K from the curing forage. Minimum critical levels for cattle are in the range of 0.5 to 1% of forage (5 to 10 g/kg). During summer, forage with 2% K (20 g K/kg DM) may be desired to reduce heat stress in cattle. Prudent applications of K fertilizer are required to meet plant growth requirements, and not aggravate the risk of lowered Mg and Ca uptake by plants and absorption by animals.

An alternative to fertilization or direct supplementation may be to increase Mg in forage through plant breeding. Scientists have made progress with Italian ryegrass *(Lolium multiflorum)*, perennial ryegrass *(Lolium perenne)*, and tall fescue *(Festuca arundinacea)*. The new cultivars have resulted in reduced values of K/(Mg+Ca) in forage, increased blood Mg levels of grazing animals, and in high risk situations these high Mg cultivars have reduced the incidence of grass tetany and death losses in grazing animals.

Calcium and Phosphorus

Milk fever (parturient paresis, or calving fever) is a condition that mainly affects older dairy cows during early lactation. It occurs when the cow cannot replace the Ca in her body used by the initial production of milk, and is characterized by low blood Ca. The symptoms ensue relatively quickly, normally within 12 hours after calving. Early symptoms include depressed appetite, listlessness, cold ears, or dry muzzle. The clinical onset of milk fever and its symptoms can progress through three stages: 1) the cow is still standing, but shaky and uncoordinated; 2) the cow is laying down on her chest and her muscles are weak; and, 3) the cow is on her side, comatose and unresponsive, with very weak muscles. Animals must be treated with Ca for several days, but it must be administered by injection, not orally, because milk fever also halts digestive activity. Milk fever can occur even when herbage contains more the 0.4% Ca (4.4 g Ca/kg DM).

It is more important to balance the dietary Ca and P than to focus on Ca intake alone. A Ca:P ratio of 2:1 (wt:wt) is ideal, but as high as 8:1 has been tolerated. In situations where the Ca:P ratio is very high, cattle and sheep may be observed chewing on bones. This behavior may be indicative of a P deficiency. Male sheep or cattle may be more prone to kidney stones when the dietary Ca:P is less than 2:1. Supplementing Ca will reduce the incidence of this problem if the stones are analyzed as containing high concentrations of P. Knowing the approximate Ca:P ratios of feedstuffs and giving animals balanced amounts of Ca and P is another way to avoid the problems of Ca or P imbalances.

Selenium

Selenium is needed for animal health in low concentrations but is toxic at high concentrations. This is a challenging dilemma because in some regions of North America, plant Se occurs in high, potentially toxic concentrations. while in other areas, Se concentrations may be inadequate for animal requirements. Dietary Se requirements range from 0.03 to as much as 1.0 mg Se/kg DM. Selenium deficiency causes white muscle disease, ill thrift, reduced fertility, and retained placenta in animals. White muscle disease is a condition often affecting young animals where the buildup of white connective tissue in the muscles causes degeneration of the heart and skeletal muscles. Alkali disease and acute Se toxicosis (selenosis) may occur when animals ingest excess Se (> 5 mg/kg). It is characterized by hoof sloughing and malformations, loss of hair, stiff joints, and anemia, and in some cases, death. This can occur when animals are grazed in areas with high soil Se and the forage plants uptake toxic amounts of Se. Selenosis occurs when animals eat Se accumulator plants growing on Se-rich soils. Se-rich soils are often found where coal and petroleum production occurs. Seleniferous areas can often be grazed for a few weeks and then animals must be moved to areas that have reduced concentrations of Se.

The amount needed for selenium toxicosis or deficiency is dependent on the class of animal and levels of other vitamins or minerals in the diet. High levels of dietary S will counter the availability of Se to ruminants. A deficiency in vitamin E can cause the same symptoms as a selenium deficiency. Often when these symptoms are detected, both selenium and vitamin E are administered. When the symptoms of toxicosis are present, providing a feed source known to be low in Se or grown on Se-deficient soils can counter the symptoms. Another way to counteract excess Se is to increase sulfur intake or to add S to fertilizers used on Se-rich pastures.

Sulfur and Selenium Interactions

Sulfur toxicity may occur if ruminants ingest excess sulfate sulfur. The symptoms are caused when sulfate is reduced to the toxic H_2S form in the rumen, which kills rumen microflora. Symptoms include weight loss, anorexia, and possibly liver damage or breathing problems. Research indicates sulfate in drinking water should be considered suspect in these cases. Interactions of S x Se may occur when S fertilization results in forage crop yield response. This can lead to reduced Se intake or Se deficiency in the animals eating these plants.

The S x Se interaction is real, but the most important relationship is one of mistaken identity. In the early days of experimentation on toxicosis of Se accumulator plants, experimenters drenched several calves with water later identified as rich in both Glauber's salt (sodium sulfate), and Epsom salt (magnesium sulfate). One of the calves became blind and the experimenters associated the blindness with the excess Se in the plant. Since the 1990's others have shown that the "blind staggers" is caused by high levels of sulfate-sulfur in feed and especially in water. Blind staggers are often observed in animals restricted to poor quality water because of enriched levels of sulfate salts.

In some high elevation alfalfa fields, and perhaps in other situations, S may be deficient and prevent successful inoculation of the legume with N-fixing microbes. In these situations, sulfur fertilization will improve the growth of N-fixing microbes and the legume crop production will sometimes increase 2 to 3 times. However, greater forage production may dilute Se concentration in forage and Se deficiencies may be observed in cattle eating forage that received S fertilization. Another situation occurs where hay had been produced under rainfed systems and then upon irrigation the yield increased, but Se is diluted and some cattle eating this hay do not ingest sufficient Se for their needs.

Copper, Molybdenum, Sulfur, and Iron

Copper deficiencies may occur in grazing animals. Reduced bioavailability of Cu occurs in the presence of increased intake and bioavailability of Mo, S, and Fe. The formation of thiomolybdates in the gut may reduce absorption of Cu by animals. Copper requirements for cattle are about twice those for sheep. Sheep are very sensitive to moderately high Cu levels in the diet. Several incidences of Cu toxicity in grazing sheep have been reported on recently manured pastures. Research indicates these are associated with swine or poultry manures from operations where Cu-anthelmintics are used for control of intestinal parasites. Copper bioavailability differs among some grasses as scientists showed for cattle grazing tall fescue or quackgrass (Agropyron repens). Dietary Cu intake should be decreased in areas where herbage Mo levels are extremely low. When Mo levels are high, as they are in some meadow soils, then Cu supplementation should be increased. Nutritionists should be alert to signs of Cu deficiency or toxicity in animals, because of the many opportunities for interaction that affect Cu bioavailability. Blood plasma Cu should be monitored if dietary deficiency is suspected.

Silicon

Plants take up Si and deposit it in the cell walls of leaves, and especially on the leaf perimeter. These Si deposits provide physical support to plants, and reduce their susceptibility to insects and fungi. However, Si deposits may reduce livestock preference or palatability for certain plants. Silicon may also reduce digestibility of forage by: 1) acting as a varnish on the plant cell wall and reducing access to rumen microflora; 2) forming insoluble compounds with trace elements, like Zn, reducing their availability to rumen microflora; or, 3) forming compounds with enzymes involved in rumen metabolism. Other reports indicate that a water-soluble form of Si inhibits activity of some digestive enzymes, but the insoluble form is chemically inert. Therefore, Si ingested with soil or dust probably has little effect on digestibility.

Silicon, in addition to affecting forage quality, can cause animal health problems. In some early research, the incidence of stones in the urinary tracts of steers was related to Si concentrations in Montana forage grasses. Providing adequate and quality drinking water will reduce the incidence of urinary stones caused by Si. Ingestion of certain Si minerals may increase the rate of tooth wear, and reduce the effective lifetime of grazing animals.

Fluorine

Fluorine in concentrations of 1 to 2 mg F/kg, while not required by animals, is beneficial for high tooth and bone density. Concentrations of 4 to 8 mg F/kg will cause brown staining of tooth enamel and concentrations greater than 8 mg F/kg will reduce tooth and bone density and increase tendency for breakage. Drinking water is the primary source of F. Researchers believe sprinkler irrigation of forages, using high F water, is another way in which animals may ingest excess F. High F is often associated with thermal water from natural springs and with rock phosphates used for supplemental P in rations. Fluorine intake is seldom a problem for adult animals. However, intake of excess F will weaken tooth and bone formation for young growing stock and producers should consider growing these animals in other areas where F intake is not excessive.

Iodine

Research has shown animal performance can be good on pastures containing 0.3 mg I/kg DM, however, the northern half of the U.S. and Canada is generally I-deficient. Salt (NaCl) is a common carrier of supplemental I for humans and domestic livestock and will be identified as iodized salt. Dietary intakes of 1 to 2 mg I/kg DM should be considered when animals are eating goitrogenic (causing thyroid growth) plants like turnips and other mustard species.

Mineral Summary

Most livestock managers are familiar with the basic dietary mineral needs of their animals. However, it is difficult to keep track of the many interactions between minerals and their implications to animal health. One of the best ways to ensure that animals are getting adequate amounts of minerals is to provide either a mineral mix in the feed ration, or a salt and mineral block that is formulated for the needs of a specific area. With the possible exception of phosphorous, there is no evidence that animals deficient in one or more minerals, are able to identify from a cafeteria offering, that element(s) that is deficient in their diet. Once the proper amounts of minerals are available, then potential mineral imbalances should be considered and mineral ratios adjusted. Use care when applying fertilizer to pastures, and learn the general mineral contents of various feedstuffs. If a dietary mineral imbalance is suspected, examine the feed and water sources and test them for mineral content. Then treat accordingly, or consult a veterinarian or nutritionist for advice. Solving the mineral puzzle may be difficult, but will yield benefits in animal health and production.

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